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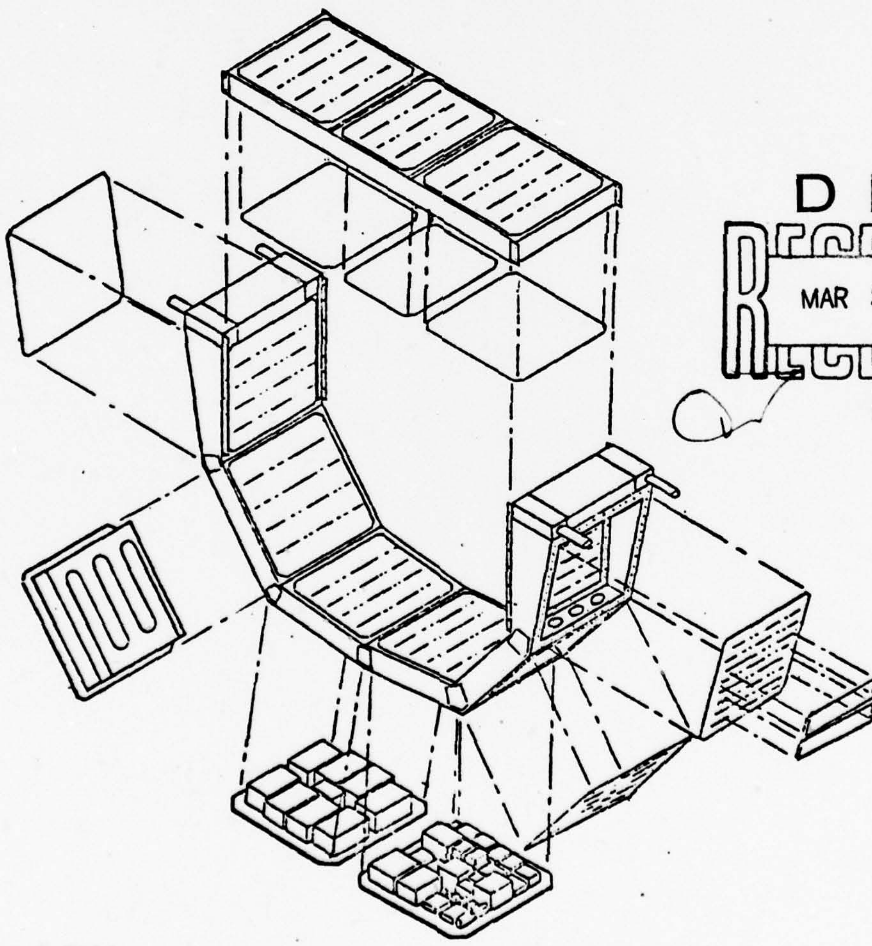
(2) LEVEL II

STANDARD TEST RACK
CONCEPT DEFINITION STUDY
STRUCTURAL ANALYSIS REPORT



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January 1979

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Contract F-04701-77-C-0116

STANDARD TEST RACK CONCEPT DEFINITION STUDY

STRUCTURAL ANALYSIS REPORT

Prepared for the

HEADQUARTERS

SPACE AND MISSILE SYSTEMS ORGANIZATION

LOS ANGELES, CALIFORNIA

Prepared by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DOD Standard Test Rack Structual/Dynamic Analysis for critical loading conditions. NASTRAN converter model developed for coupled STS/STR Transient analysis high payload weight capability of STR investigated.

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STANDARD TEST RACK

STRUCTRAL AND DYNAMIC ANALYSIS REPORT

TABLE OF CONTENTS

1.0 INTRODUCTION

This report contains the results of a structual and dynamic analysis performed on the Standard Test Rack (STR) to assess its capabilities and structural characteristics. The STR is a "D" shaped structure consisting of an arched section spanned by a moveable bridge as shown in Figure 1-1. Both the

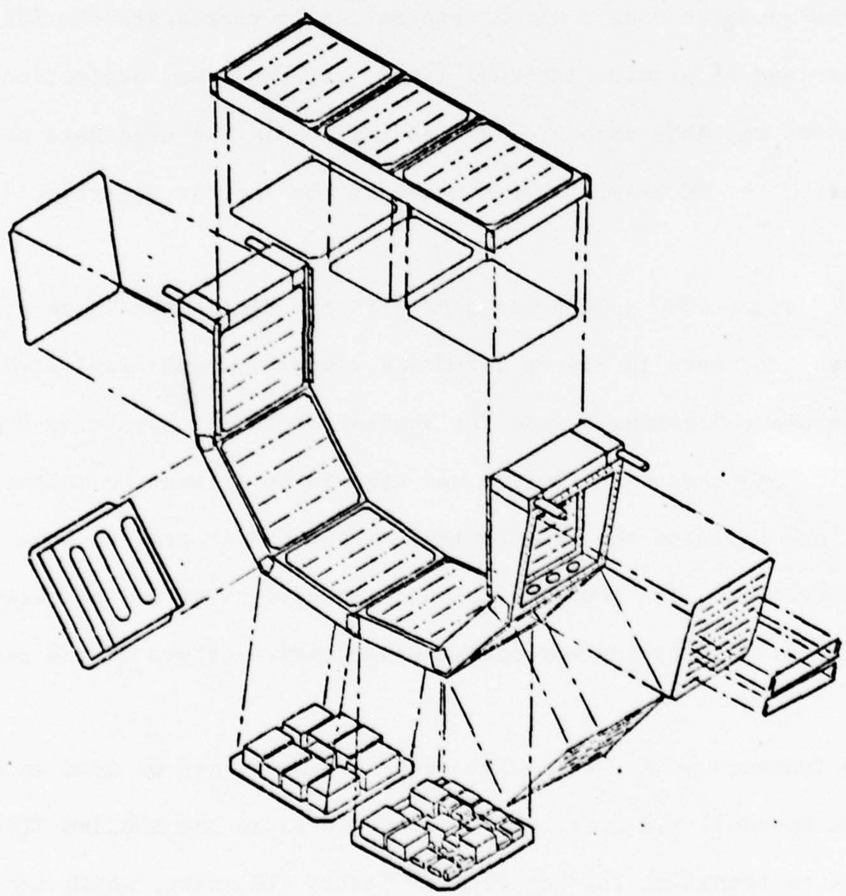


FIGURE 1-1 EXPLODED VIEW OF STANDARD TEST RACK

bridge and basic strongback are made up of box sections to obtain the strength/ stiffness of a torque box. Each of these box sections are composed of two, nine inch channels, two large panels and two interior phear webs. One of the panels is heavily stiffened to carry payload components or housekeeping equipment. The other panel is lightly stiffened and is used primarily to carry in plane loads.

A NASTRAN computer model, which mathematically represents the STR, was developed and exercised to provide internal loads, stresses, and deflections, natural frequencies and mode shapes. The loading conditions used were obtained from Ref. 3 — ICD2-19001 which provides the shuttle interface data.

A total mass of 6000 pounds was used with the STR in the "High Bridge" configuration shown in Figure 1-2 with a gimbal system - Payload Orientation and Instrument Tracking System for Shuttle (POINTS) supporting a heavy payload. This mass distribution was used in an attempt to maximize the stress (and minimize the frequencies) in the STR to provide some measure of conservatism. The low damping and high margins of safety based on ultimate loads are also an indication of the conservative nature of the results.

The STR dynamics model, which has been developed, can be used in conjunction with the Rockwell STS model in order to determine the coupled STS/STR dynamic response to transient loading events. Twenty STR modes, which include all natural frequencies below 100 Hz, will be sufficient to define the dynamic characteristics of the STR. Because of this realively low number of modes meeded to define the STR, configurations with multiple STR's in the shuttle cargo bay can be readily analyzed.

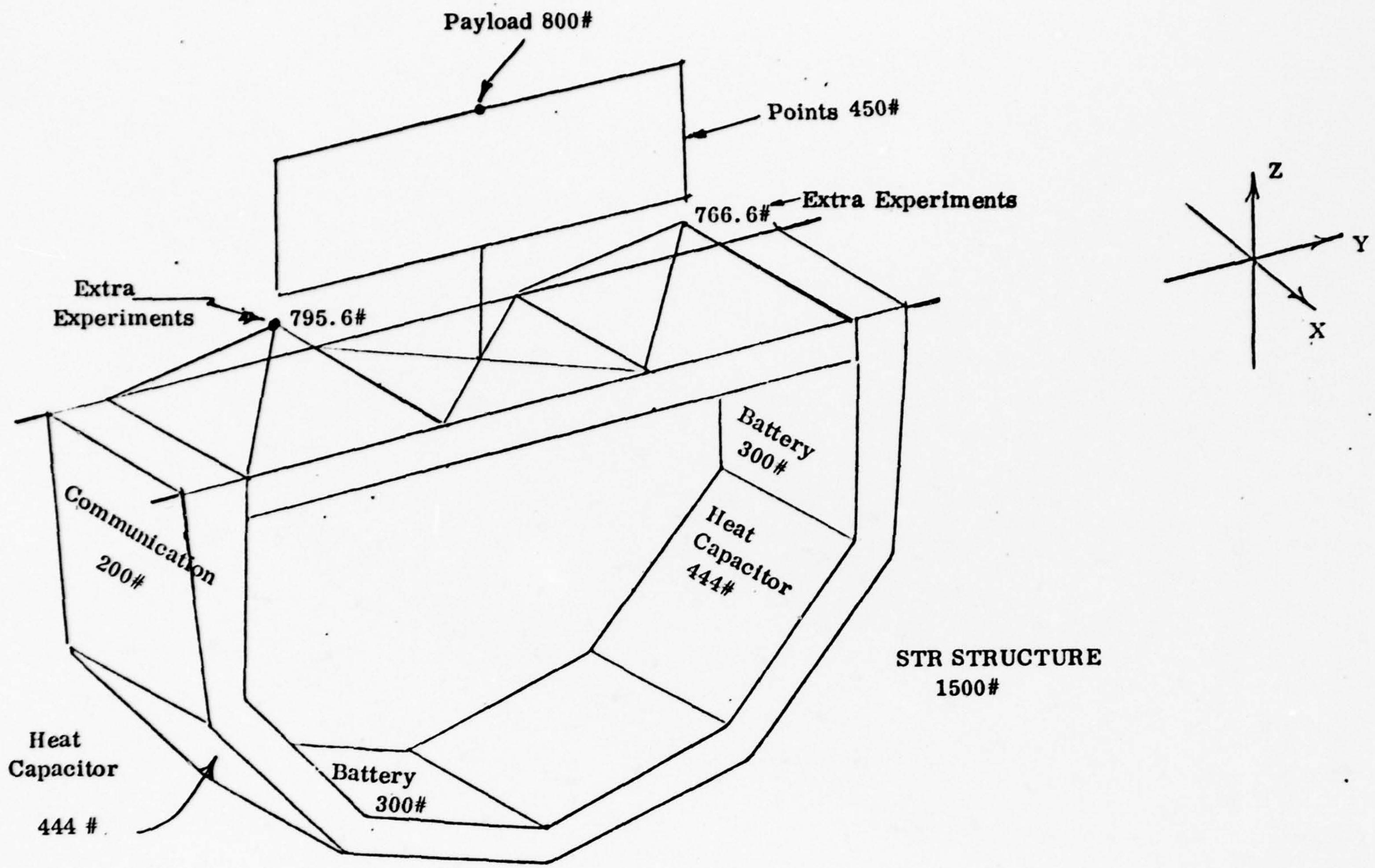

Payload 800#
Points 450#
766.6#
Extra Experiments
Extra Experiments
795.6#
Z
Y
X
Battery 300#
Heat Capacitor 444#
Communication 200#
Heat Capacitor 444 #
Battery 300#
STR STRUCTURE 1500#

FIGURE 1-2

2.0 RESULTS

The results of the stress and dynamic analyses performed on the STR show that the STR can survive greater than twice the ultimate loads predicted by Ref. 3. All margins of Safety calculated based on those ultimate loads are $\geq$ 1.0 as shown in Table 2-1.

Natural frequencies and mode shapes were calculated and are described in table 2-2. All natural frequencies are greater than the 6.5 Hz shuttle requirement.

Frequency response characteristics were determined for a 1g base excitation loads. The maximum responses are shown in Table 2-3.

All of the above analyses were performed utilizing a NASTRAN model of the STR structure with a 6000 pound weight distribution arranged to provide maximum stress to the STR members as shown in Figure 1-2.

TABLE 2-1

STANDARD TEST RACK MINIMUM MARGINS OF SAFETY
(FLIGHT CONFIGURATION)

ITEM	LOAD CASE	MATERIAL	FAILURE MODE	MS
Equipment Panel	5	6061-T6	Crippling	1.00
Shear Panel	7	6061-T6	Crippling	1.38
Component Mounting	-	6061-T6	Bending	1.05
9" Channel (Arch Member)	8	6061-T6	Crippling	1.12
9" Channel (Bridge Member)	8	6061-T6	Crippling	6.4
Keel Trunnion Fitting	4 & 5	An-Steel (Bolt)	Bolt Shear	1.50
4 Top Trunnion Fittings	6 & 7	An-Steel (Bolt)	Bolt Shear	>1.00
Bridge Fitting	6	An-Steel (Bolt)	Bolt Shear	>1.00
Web Knee Fitting	8	6061-T6	Bending	1.00

HIGH PAYLOAD CONFIGURATION 5000LB

Table 2-2 STR Natural Modes Summary

MODE	FREQ (HZ)	TYPE MOTION
1	7.60	POINTS TORSION
2	8.47	STR - LATERAL
3	13.54	STR - PITCH
4	14.21	BRIDGE BENDING/VERTICAL
5	16.49	POINTS LATERAL BENDING
6	16.81	STR - LONGITUDINAL
7	25.19	STR - ROLL
8	30.31	TORSION ABOUT KEEL SUPPORT
9	38.01	-
10	39.06	-
⋮	⋮	⋮
20	92.53	-
⋮	⋮	⋮
50	327.8	-
⋮	⋮	⋮

Table 2-3 Estimate of Payload Transient Vibration Environment

Component	Peak Acceleration 0-35 Hz, One-G Input	Peak Acceleration 1/4 G Input (Est. Transient)	Peak Acceleration 1/4 G Input +6 dB For Component Testing
Points Payload (800#) (Node 53)	24 g	6	12
Bridge Payload (796#) (Node 44)	20 g	5	10
Equipment Panel Center (Node 26, 89#)	20g	5	10

MIL STD 1540A Specifies 20g Minimum

3.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions drawn from the stress analysis are:

1. The STR can survive greater than twice the ultimate loads predicted for shuttle payloads by Ref. 3.

2. Slight modifications are required to the protoflight structure to achieve flight status.

The conclusions drawn from the dynamics study are:

1. A 165 degree of freedom model of the STR in a high payload configuration has been developed. The model can be used to:

   (a) Furnish STR dynamic characteristics for transient analysis of the coupled STS/STR.
   (b) Serve as a point of departure for future analyses of other STR payload configurations.

2. Relatively few modes ($\approx$20) are necessary to define the STR for the coupled STS/STR transient analysis. This is significant because, typically, payload contractors are limited to 150 degrees of freedom. Shuttle configurations having more than one STR can be analyzed without approaching this limitation.

3. The STR frequency response to one-g, rigid-body, sinusoidal acceleration inputs has been determined. Major response modes have been identified and the vibration environments of payloads have been defined. These vibration environments were found to be below the 20 g minimum acceleration specified in MIL-STD-1540A.

4. Component random vibration specifications have been developed from the STR acoustic test (Ref. 2).

The following recommendations for future efforts are made:

1. Perform a final stress analysis once the final production drawings are complete.

2. Modify the protoflight vehicle in accordance with the enclosed stress analysis.

3. Generate a Loads Transformation Matrix for the STR and perform a coupled STR/STS transient analysis. The transient solution would be obtained by Rockwell-Downey using their dynamic model of the STS.

4. Investigate the design of an integrally damped bridge structure to attenuate the dynamic response of payloads supported by the bridge. Pursue to design of integrally damped component panels.

5. Perform a modal vibration test of the STR. This would serve as a reference for future dynamic analyses, aid in the design of a damped structure, and provide measured values of modal damping. The modal damping measurements have two important applications:

   (a) Input definitions to the STS/STR transient analysis.
   (b) Re-calculation of the frequency response to rigid-body accelerations with actual damping values. (The initial analysis assumed 2.5 percent critical damping in all modes). The envelope of the frequency response is greatly effected by the levels of modal damping and hence accurate values are required.

6. Develop a more detailed dynamics model for the component panels.

4.0 SUPPORTING DATA

4.1 NASTRAN Computer Model of STR

A NASTRAN Computer Model which mathematically represents the STR was developed. The model consists of:

141 Grids
193 Plates
126 Beams
8 Rods
55 Mass prints

Computer plots of the model are shown in Appendix A along with details of the mass distribution.

A mass distribution of 6000 pounds was selected. The configuration shown in Figure 1-2 includes a pointing system weighting 450 pounds with an 800 pound payload mounted with it. Additional payload equipment of 1562 pounds is also mounted to the bridge and its distribution was adjusted so that the total load would react through the centroid of the Space Transportation System (STS). Subsystem support equipment of 1685 pounds and the STR structual weight of 1500 pounds complete the total of 6000 pounds. This mass distribution was chosen man attempt to maximize the stress and minimize the frequencies to afford some degree of conservation.

Figure 4.1-1 shows the mass point designation used for the dynamic analysis.

4.2 LOADING CONDITIONS

All loads were applied as mass to the structure and the model was then exercised for the following loading conditions shown in Table 4.2-1. Aside from the 1g conditions, all load conditions were obtained from Ref. 3.

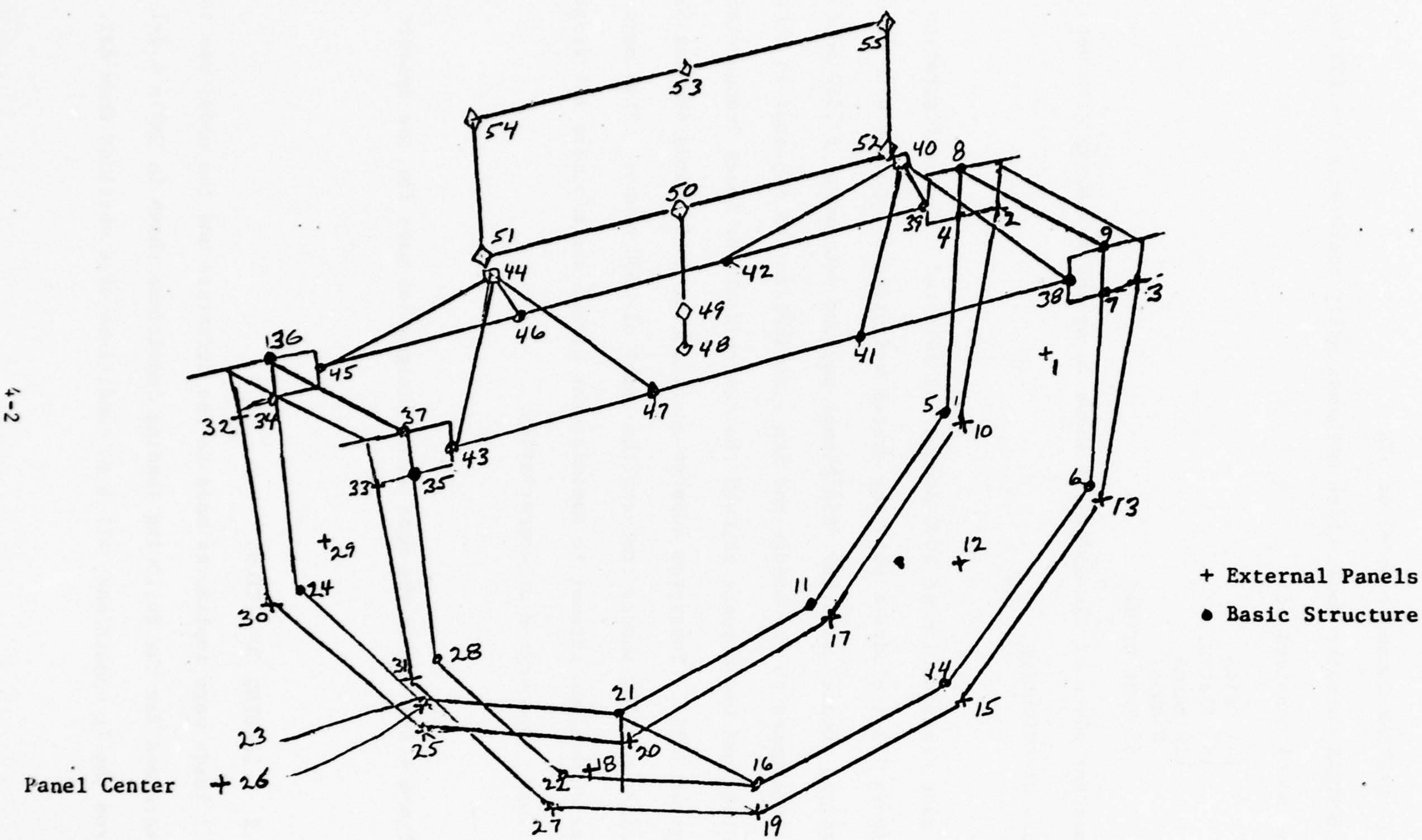


Figure 4.1-1 Nodes Points of Dynamic Model

Conditions 1,2 & 3 are simply one g accelerations in each of the three orthegonal directions and were used to check the model and provide preliminary estimates of the fundamental natural frequencies.

Conditions 9,10 & 11 are the crash ultimate conditions in each of the three orthogonal directions delineated in Ref 3.

Conditions 4,5,6,7 & 8 were selected from Ref 3 as being the most critical loading maneuvers. It should be noted that the associated angular accelerations were not included since they were investigated for the most critical case and found to be negligible when compared to the translational accelerations. In order to increase the loads to ultimate, the recommended 1.4 factor was used and is included in Table 4.2-1.

ACCELERATIONS

Load Case No	G-Forces & Direction	Description
1	IX	1G-X Direction
2	IY	1G-Y Direction
3	IZ	1G-Z Direction
4	1.26X 1.75Y 1.4Z	Descent Yaw Maneuver X1.4 (Ultimate)
5	1.26X-1.75Y 1.4Z	"
6	-4.48X -1.4Y -3.5Z	Ascent Lift-Off X1.4 (Ultimate)
7	2.62X 1.4Y 5.88Z	Descent Landing X1.4 (Ultimate)
8	2.52X-1.4Y 5.88Z	Descent Landing X1.4 (Ultimate)
9	4.5X	Crash Ultimate
10	1.5Y	Crash Ultimate
11	4.5Z	Crash Ultimate

TABLE 4.2-1 STS/STR LOADING CONDITIONS

4.3 Margins of Safety

Using the NASTRAN model described in section 4.1 and exercising it for the critical loading conditions given in section 4.2, the resultant internal loads and deflections were obtained for all of the members. Utilizing, this data, a stress analysis of all the key structual members of the STR was performed and the resultant margins of safety are shown in Table 4.3-1. It can be seen that all margins of safety are greater than 1.0. In addition, built into the loading conditions described in section 4.2 is the NASA recommended factor of safety of 1.4 for ultimate loads. Another way of stating it is that <u>the STR can survive>twice the conservative ultimate loads</u> predicted by Ref. 3.

During the analysis of the existing protoflight structure, it was found that to achieve the M.S.$\geq$ 1.0, it was necessary to make some small modifications. These changes consist of (1) using NAS 1588-5 bolts in the upper trunnion fitting rather than the planned AN-5 bolds; (2) using EWSB 922-6 alloy steel bolts (3/8") in the bridge fitting rather than the planned AN-S (5/16") bolts; (3) add an angle doubler 3¼" long and extend existing doubler on upper trunnions; (4) increase thickness of knee fitting from 0.25" to 0.28"; (5) add a 0.10" thick radius block on other side of knee fitting.

As can be seen, all of these changes are minor in nature with little or no impact to the existing structure. In addition, all modifications can be easily made on the existing protoflight structure.

4.4 Natural Frequencies and Mode Shapes

The first several natural frequencies of the STR are summarized in Table 4.4-1. The lowest natural frequency, a POINTS mode, 7.60 Hz, is above the 6.5 Hz minimum required for the shuttle. The first major STR mode is even higher at 8.47 hz.

Table 4.3-1

STANDARD TEST RACK MINIMUM MARGINS OF SAFETY
(FLIGHT CONFIGURATION)

ITEM	LOAD CASE	MATERIAL	FAILURE MODE	MS
Equipment Panel	5	6061-T6	Crippling	1.00
Shear Panel	7	6061-T6	Crippling	1.38
Component Mounting	-	6061-T6	Bending	1.05
9" Channel (Arch Member)	8	6061-T6	Crippling	1.12
9" Channel (Bridge Member)	8	6061-T6	Crippling	6.4
Keel Trunnion Fitting	4 & 5	An-Steel (Bolt)	Bolt Shear	1.50
4 Top Trunnion Fittings	6 & 7	An-Steel (Bolt)	Bolt Shear	>1.00
Bridge Fitting	6	An-Steel (Bolt)	Bolt Shear	>1.00
Web Knee Fitting	8	6061-T6	Bending	1.00

Table 4.4-1 STR Natural Modes Summary

MODE	FREQ (HZ)	TYPE MOTION
1	7.60	POINTS TORSION
2	8.47	STR - LATERAL
3	13.54	STR - PITCH
4	14.21	BRIDGE BENDING/VERTICAL
5	16.49	POINTS LATERAL BENDING
6	16.81	STR - LONGITUDINAL
7	25.19	STR - ROLL
8	30.31	TORSION ABOUT KEEL SUPPORT
9	38.01	-
10	39.06	-
⋮	⋮	⋮
20	92.53	-
⋮	⋮	⋮
50	327.8	-
⋮	⋮	⋮

Three dimensional mode shapes for the first 8 modes appear in Figures 4.4-1 to 4.4-8. The X,Y and Z components of the eigenvectors are represented by a vector triad drawn at each mass location. (Components are omitted if their magnitude is too small to draw an arrowhead).

The natural modes determined in this analysis can be used in conjunction with the Rockwell STS dynamic model to compute the coupled STS/STR response to transient loading events. Modifications to the model to account for different configurations can be readily made. Typically, the predominant shuttle transient response is below 25 Hz so that relatively few STR modes are needed for the transient analysis. Note from Table 4.4-1 that all modes below 100Hz are represented by the first 20 modes, which should be more than ample for the transient analysis. Therefore, since contractors are usually allowed 150 degrees of freedom, there is no size limitation in analyzing STS configurations having one (or <u>more</u>) STR's in the cargo bay.

A summary of the data transmittal requirements (from GE to Rockwell) for the transient analysis is shown in Figure 4.4-9. The major item yet to be generated is a suitable Loads Transfermation Matrix (LTM) from which critical loads, stresses and deflections can be derived from the modal responses.

4.5 Frequency Response Characteristics

The natural modes from the NASTRAN analysis have been used to determine frequency response characteristics of the STR. One g sinusoidal, rigid-body acceleration inputs were applied along the X, Y, and Z axes and the corresponding physical accelerations were determined at each node point for a frequency range of 5 to 165 Hz. A structural damping coefficient of G = .05 (critical damping ratio of .025) was conservatively used in the analysis.

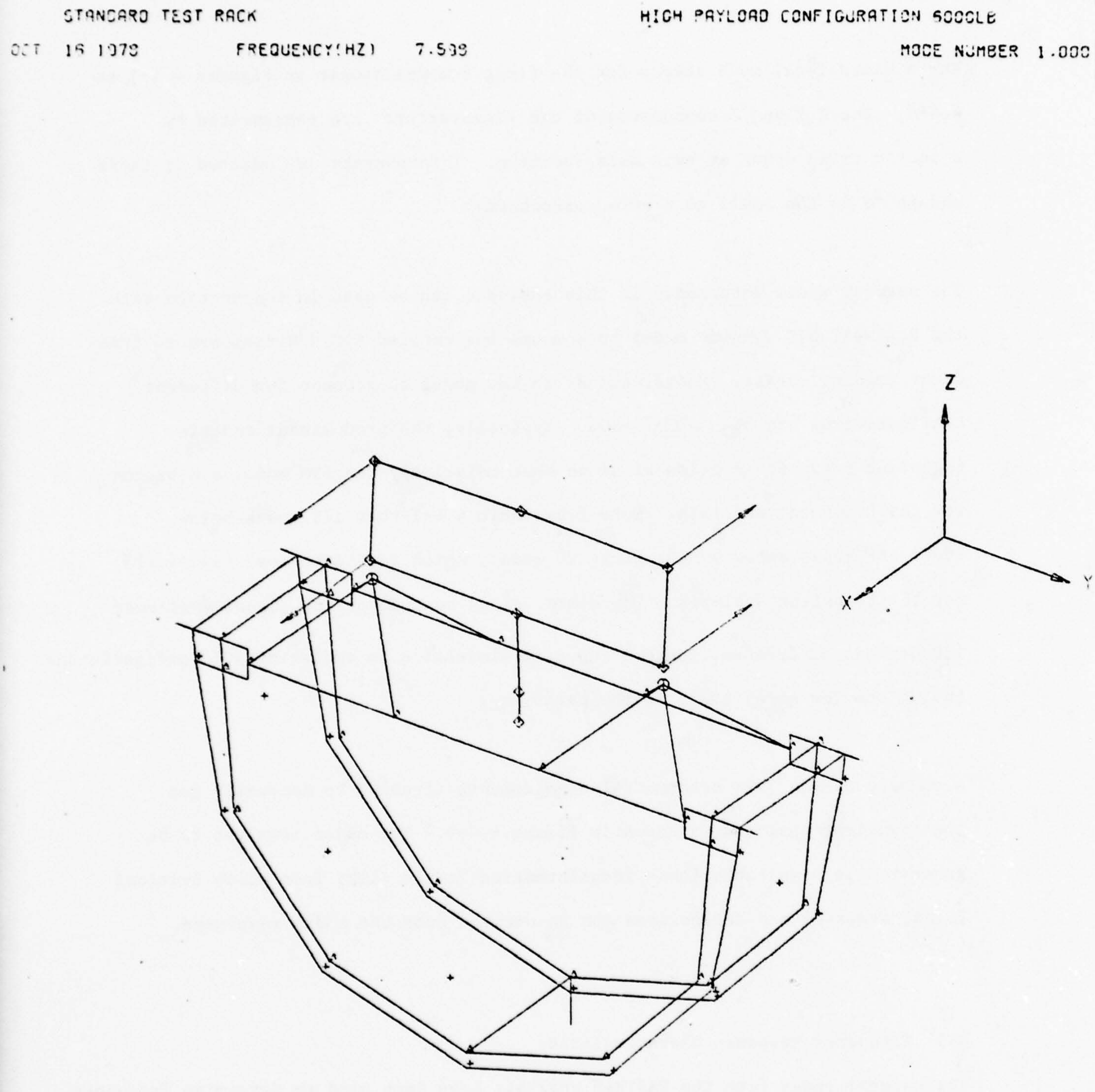


Figure 4.4-1 Mode 1 - POINTS Torsion

STANDARD TEST RACK HIGH PAYLOAD CONFIGURATION 8000LB

OCT 15 1978 FREQUENCY(HZ) 8.473 MODE NUMBER 2.000

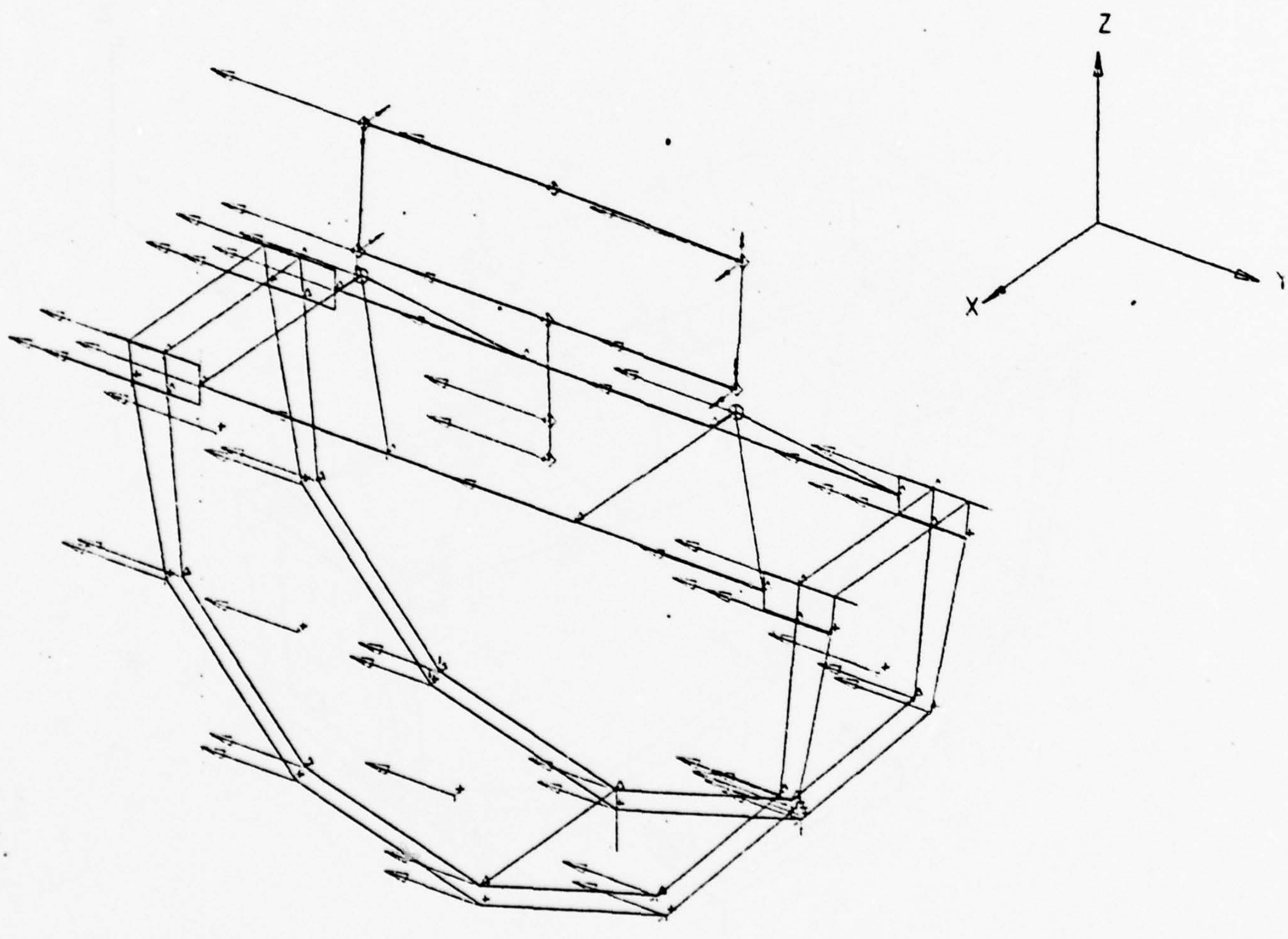


Figure 4.4-2 Mode 2 - STR Lateral

STANDARD TEST RACK HIGH PAYLOAD CONFIGURATION 6000LB

T 16 1978 FREQUENCY(HZ) 13.538 MODE NUMBER 3.000

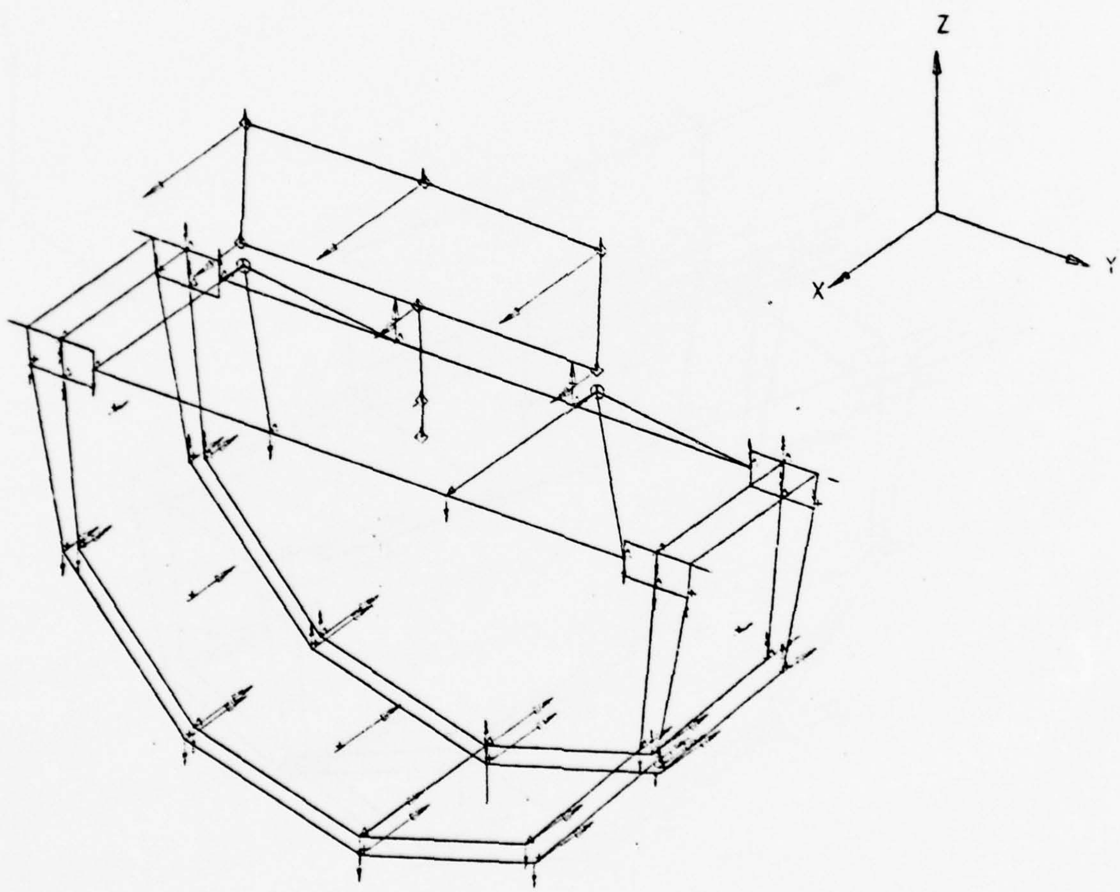


Figure 4.4-3 Mode 3 - STR Pitch

STANDARD TEST RACK HIGH PAYLOAD CONFIGURATION 6000LB

OCT 16 1979 FREQUENCY(HZ) 14.206 MODE NUMBER 4.000

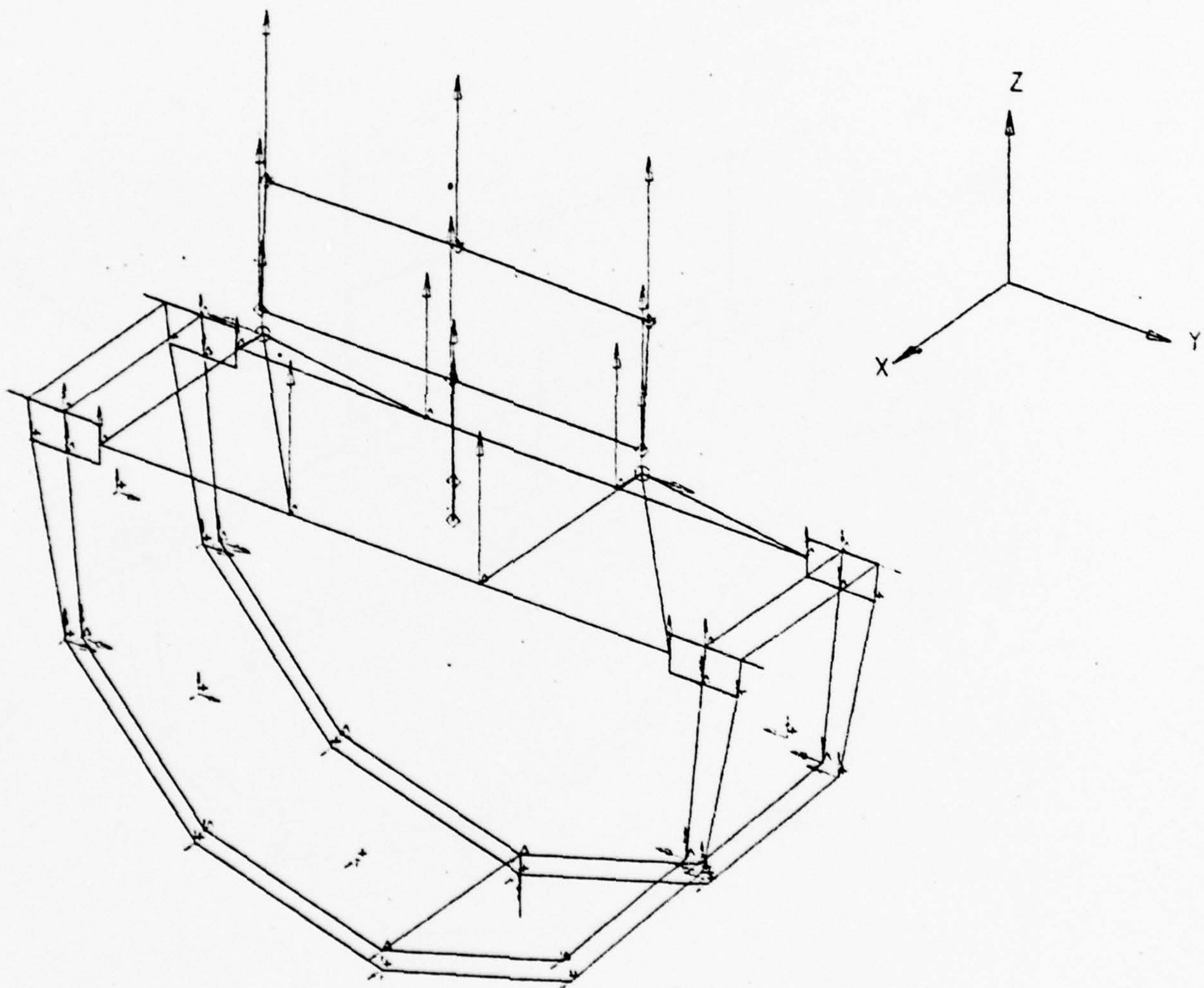


Figure 4.4-4 Mode 4 - Vertical Bridge Bending

STANDARD TEST RACK HIGH PAYLOAD CONFIGURATION SOOOLB

OCT 16 1978 FREQUENCY(HZ) 16.487 MODE NUMBER 5.000

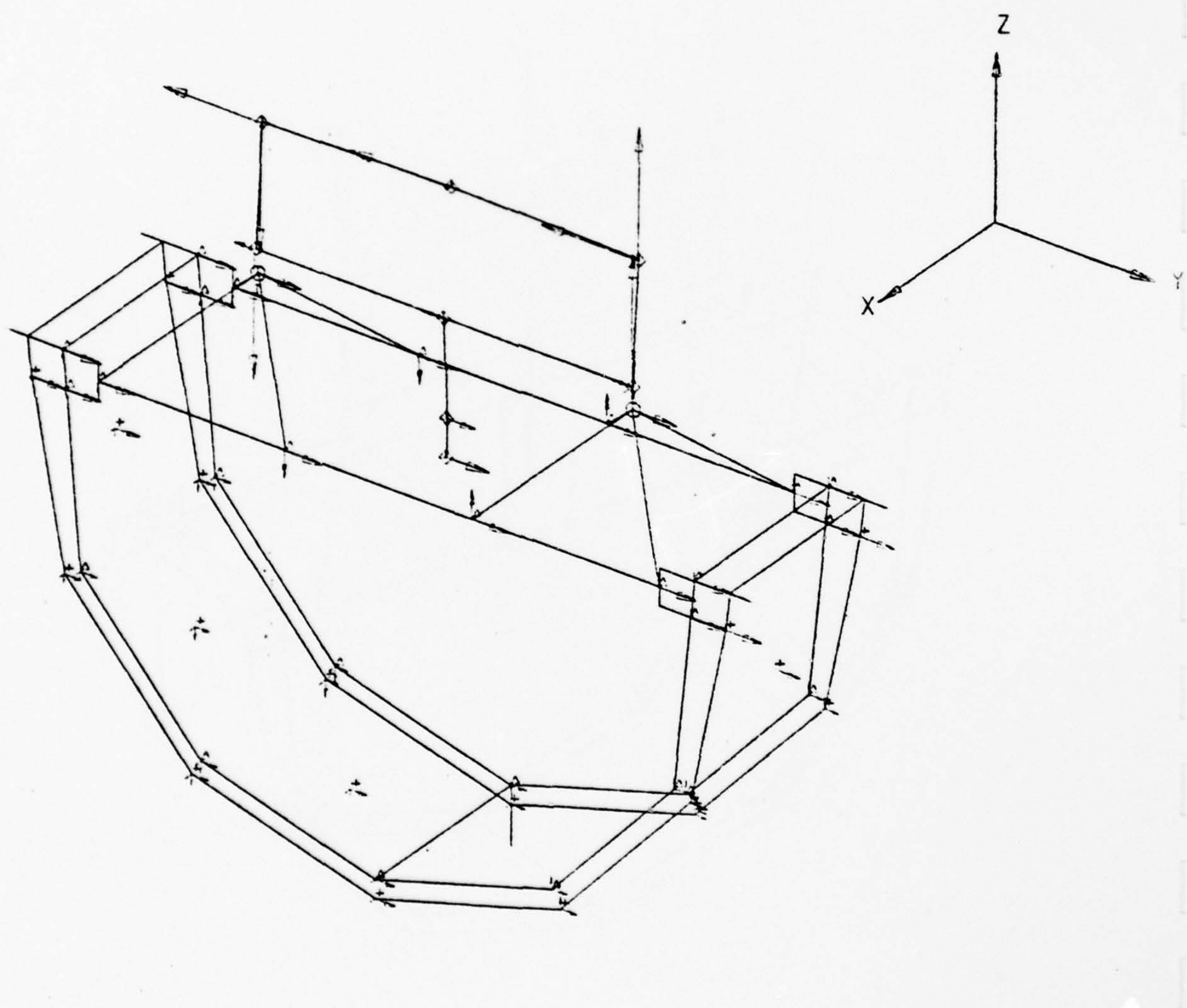


Figure 4.4-5 Mode 5 - POINTS Lateral Bending

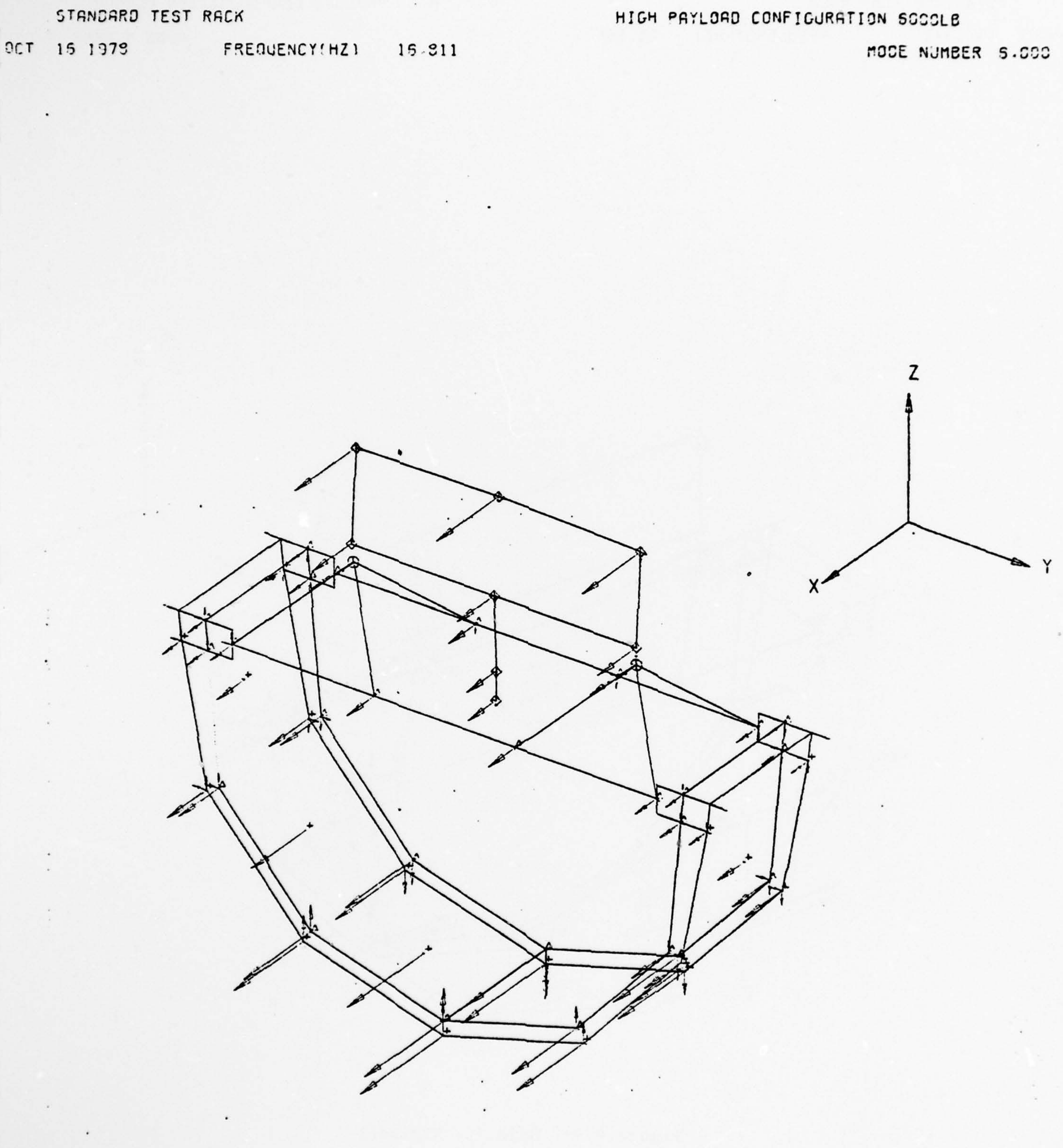


Figure 4.4-6 Mode 6 - STR Longitudinal

STANDARD TEST RACK HIGH PAYLOAD CONFIGURATION 5000LB

OCT 15 1978 FREQUENCY(HZ) 25.185 MODE NUMBER 7.000

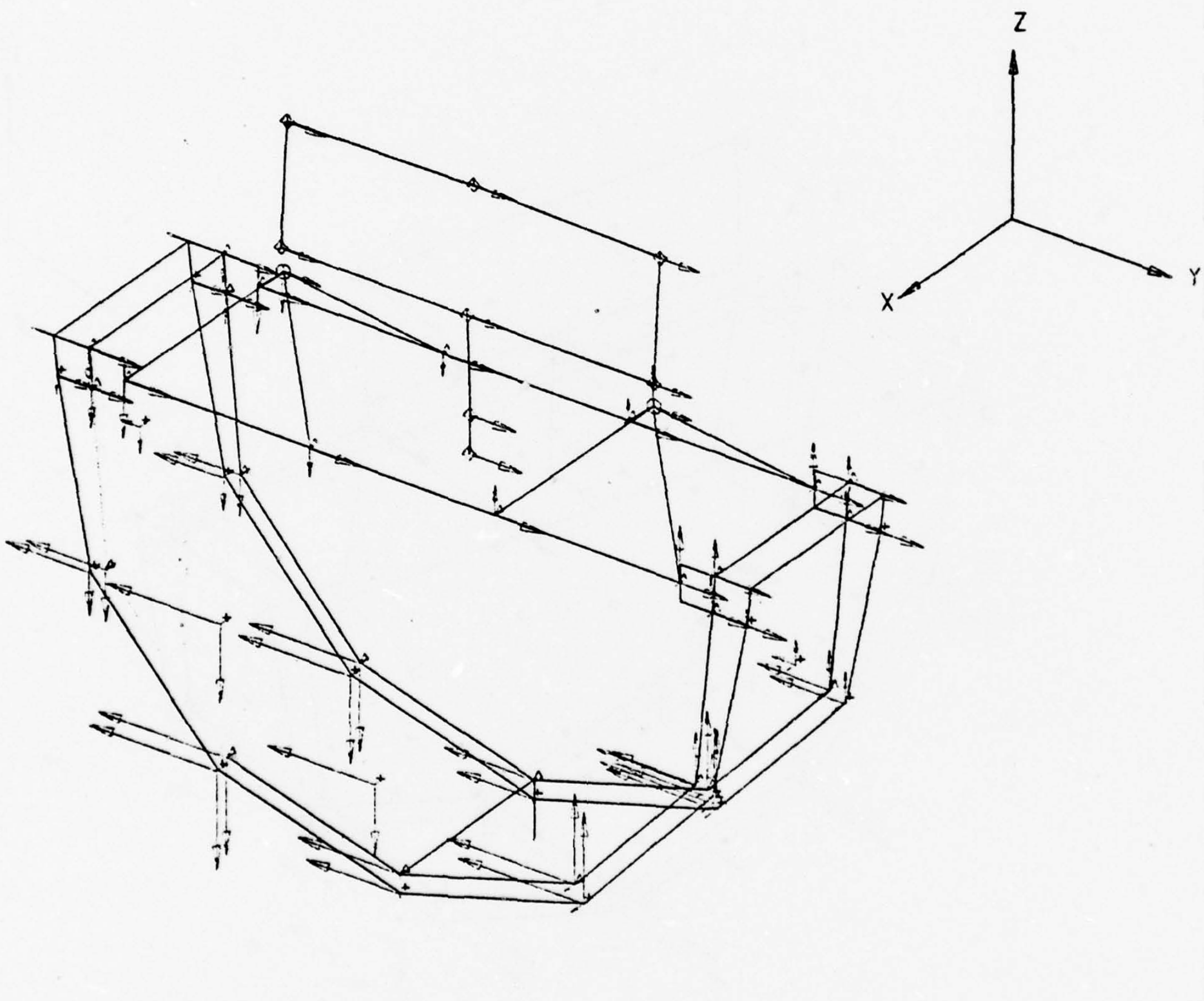


Figure 4.4-7 Mode 7 - STR Roll

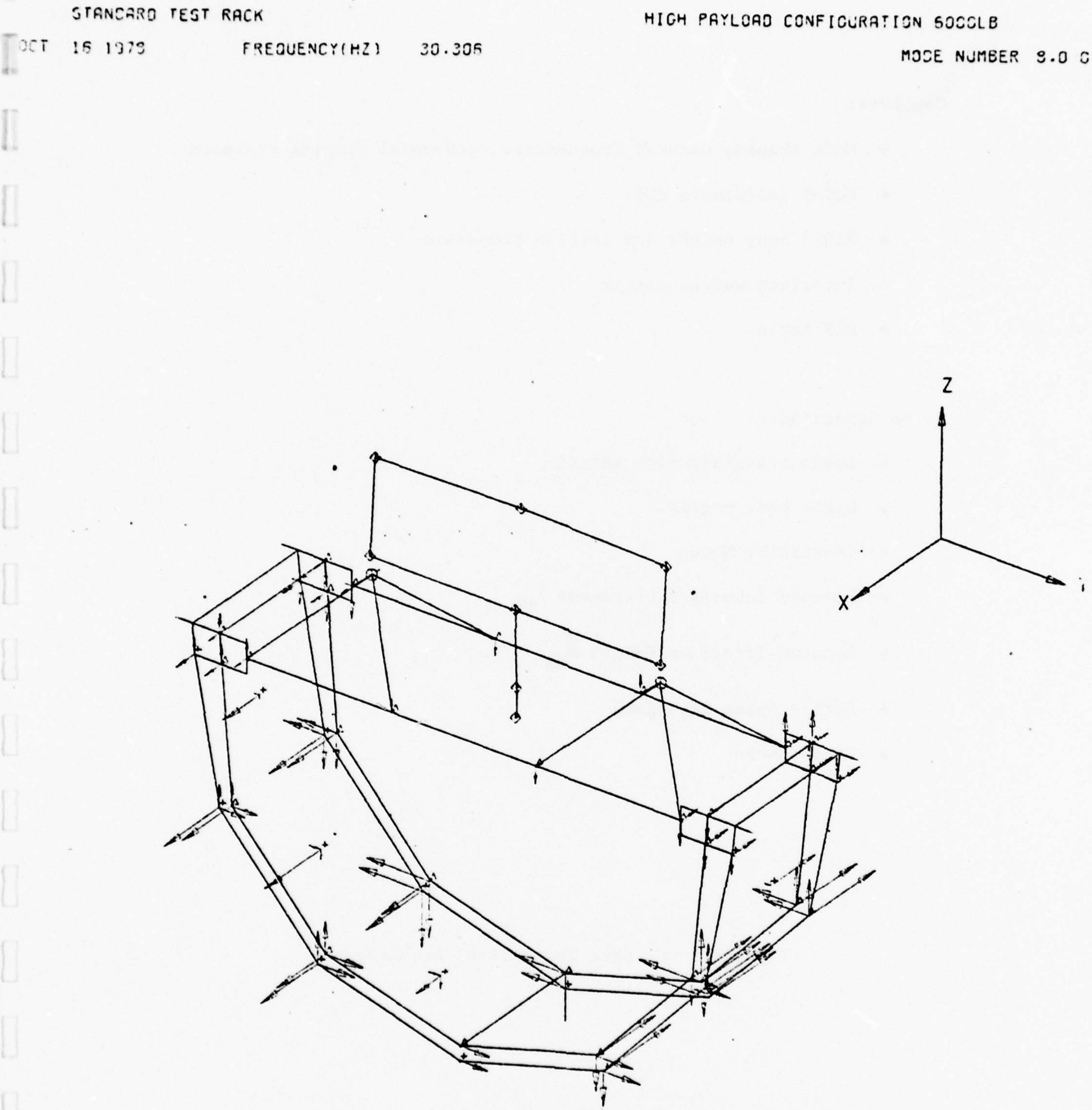


Figure 4.4-8 Mode 8 - Torsion About Keel Support

Complete:

- Mode shapes, natural frequencies, and modal damping estimate
- Nodal coordinate data
- Rigid body weight and inertia properties
- Interface weight matrix
- DOF table

To be Generated:

- Loads transformation matrix
- Rigid body matrix
- Constraint Modes
- Reduced Interface Stiffness $\overline{K}_{BB}$
- Reduced Interface Weight $\overline{M}_{BB}$
- Rattle Space Equations
- Data Checks

Figures 4.4-9 Data Transmittal Requirements

Major system resonances are summarized in Table 4.5-1. The vibration environment at the POINTS Payload location (node 53), for one-g inputs along the X,Y and Z axes are summarized in Figures 4.5-1 thru 4.5-3, respectively. Envelopes to 35 Hz of the primary response have been included in each plot. It should be noted that the maximym response in the y (lateral) direction for frequencies above 40 Hz occurs for acceleration inputs in the Z direction. This coupling was also observed at other payload and equipment mounting points. It should be taken into account in generating vibration specifications.

Similar one-g response plots for a quadrapod payload (node 44) and component panel center (node 26) appear in Figures 4.5-4 thru 4.5-9. The overall vibration levels at the POINTS payload appear to be highest of the three locations. It is felt that these could be lowered, particularly at the low frequencies where bridge bending occurs, by damping treatment of the bridge structure. This will be extremely helpful in transient loading conditions as well as in frequency response. Furthermore, it is felt that equipment panels will also benefit from damping.

It should be emphasized that the following two conditions are implicit in these analytical resutls:

(1) Because of the multipoint attachment of the STR to the shuttle it is implied that the acceleration inputs are translational, having no angular acceleration components. In particular, it is implied that an input acceleration along any given axis is the same at all attachment points which restrain motions along that axis; while the motion is zero at restraints in the remaining two directions. For example, an input acceleration in the X-direction is equal to that experienced at the two trunnions which restrain X-motions, while it is implied that z motion at the trunnions and y motion at the keel are all zero.

(2) A critical damping ratio of 2.5 percent was assumed for all modes. The response envelopes are highly dependent on the modal damping, and a modal test should be conducted to determine actual STR damping levels so that more accurate results can be obtained.

Table 4.5-1 Major Resonances for Sinusoidal Acceleration Inputs

Frequency (Hz)	Mode No.	Q*	Acceleration Input
13.5	3	5.	X-Axis (Longitudinal)
16.8	6	23	
30.3	8	1.5	
38.0	9	13	
49.6	12	2.1	
123	25	.8	X-Axis (Longitudinal)
8.47	2	23	Y-Axis (Lateral)
16.5	5	3	
25.2	7	2.6	
47.8 **	11	.9	
49.6	12	.6	
52.2	13	.2	Y-Axis (Lateral)
14.2	4	24	Z-Axis (Vertical)
47.8	11	18	Z-Axis (Vertical)
77.0	18	2.5	Z-Axis (Vertical)

* Max of POINTS Payload (Node 53), Bridge Payload (Node 44) and Panel Center (Node 26).

** Z Response

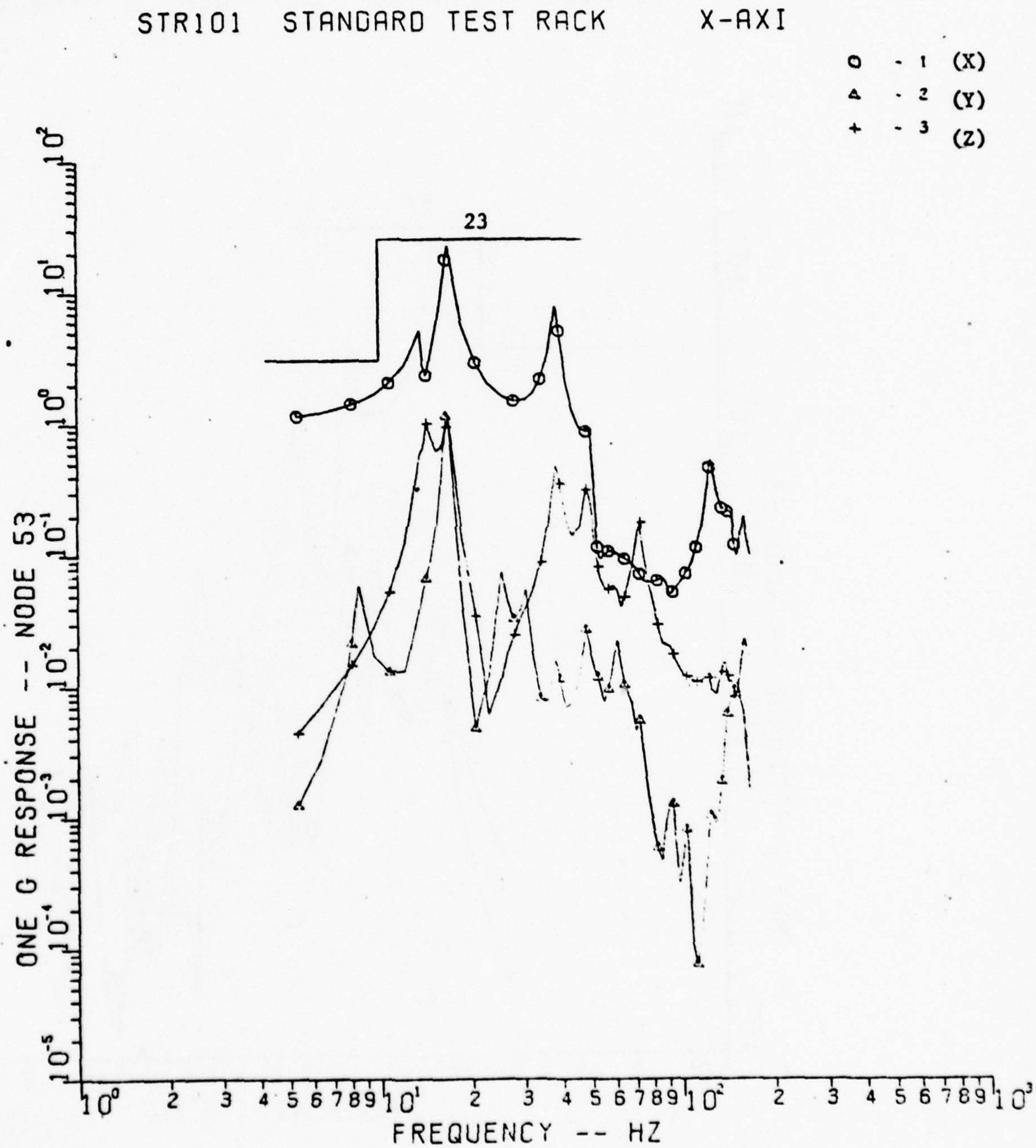


Figure 4.5-1 POINTS Payload Frequency Response for 1G X-Axis Acceleration Input

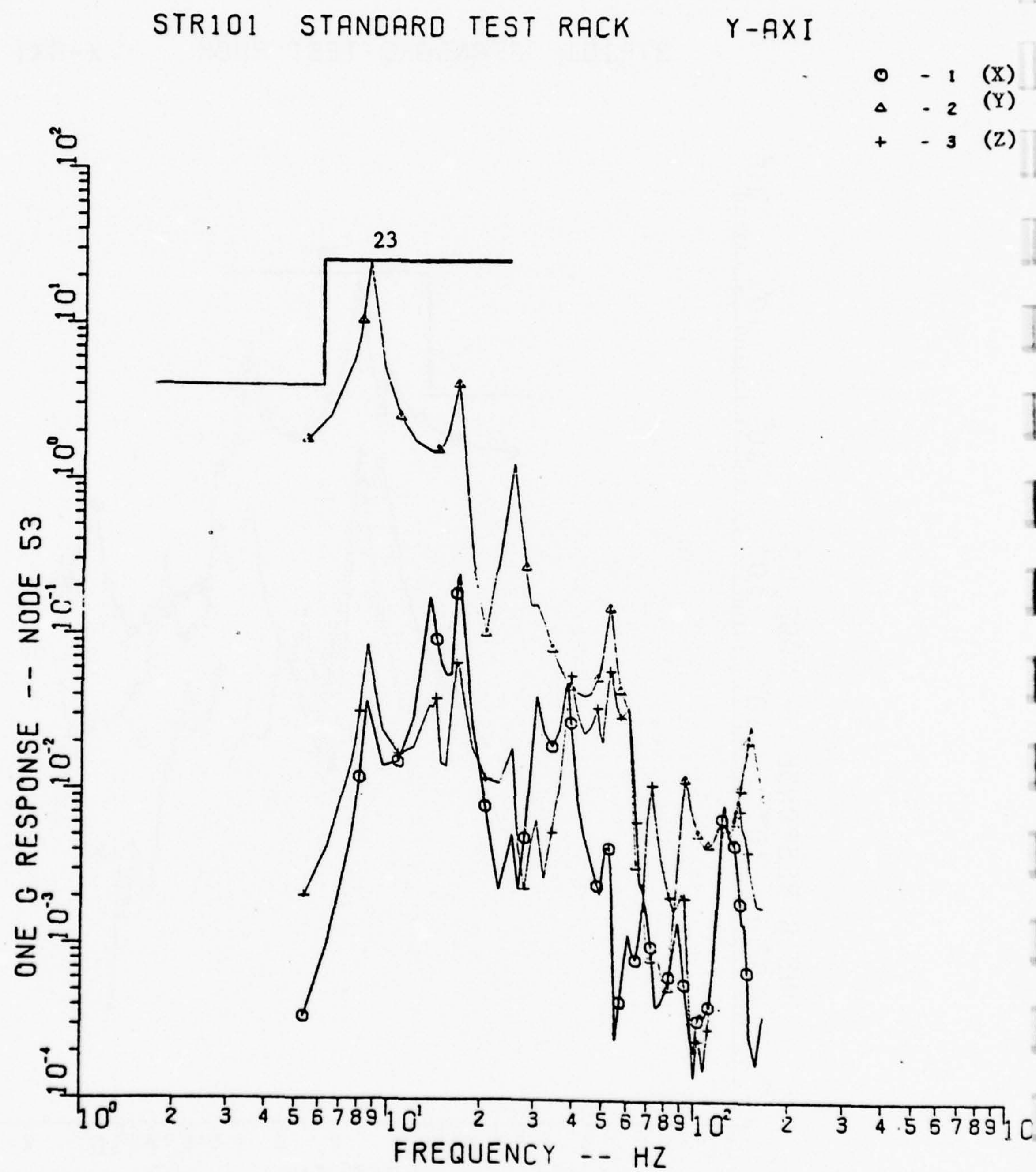


Figure 4.5-2 POINTS Payload Frequency Response for 1G Y-Axis Acceleration Input

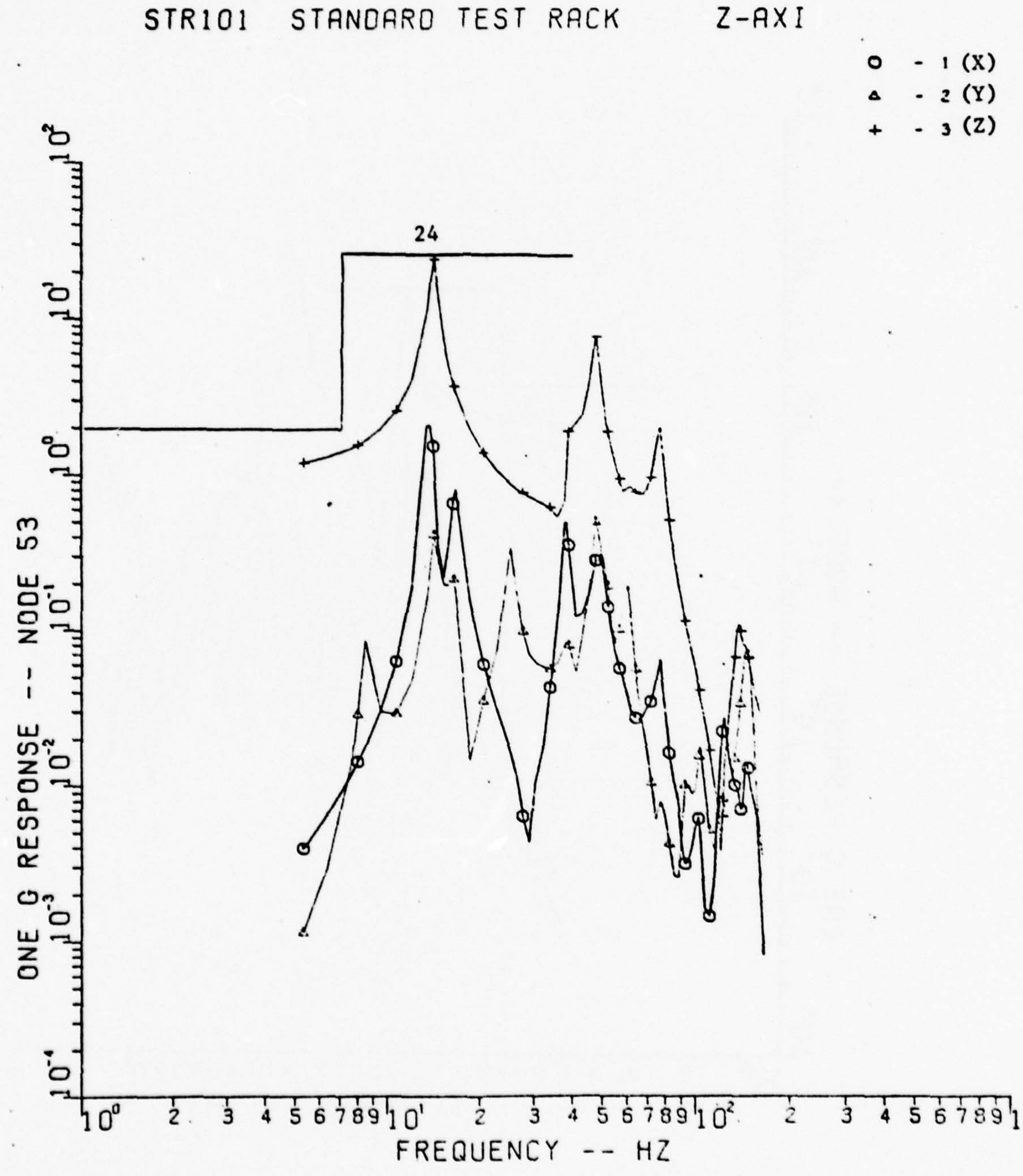


Figure 4.5-3 POINTS Payload Frequency Response for 1G Z-Axis Acceleration Input

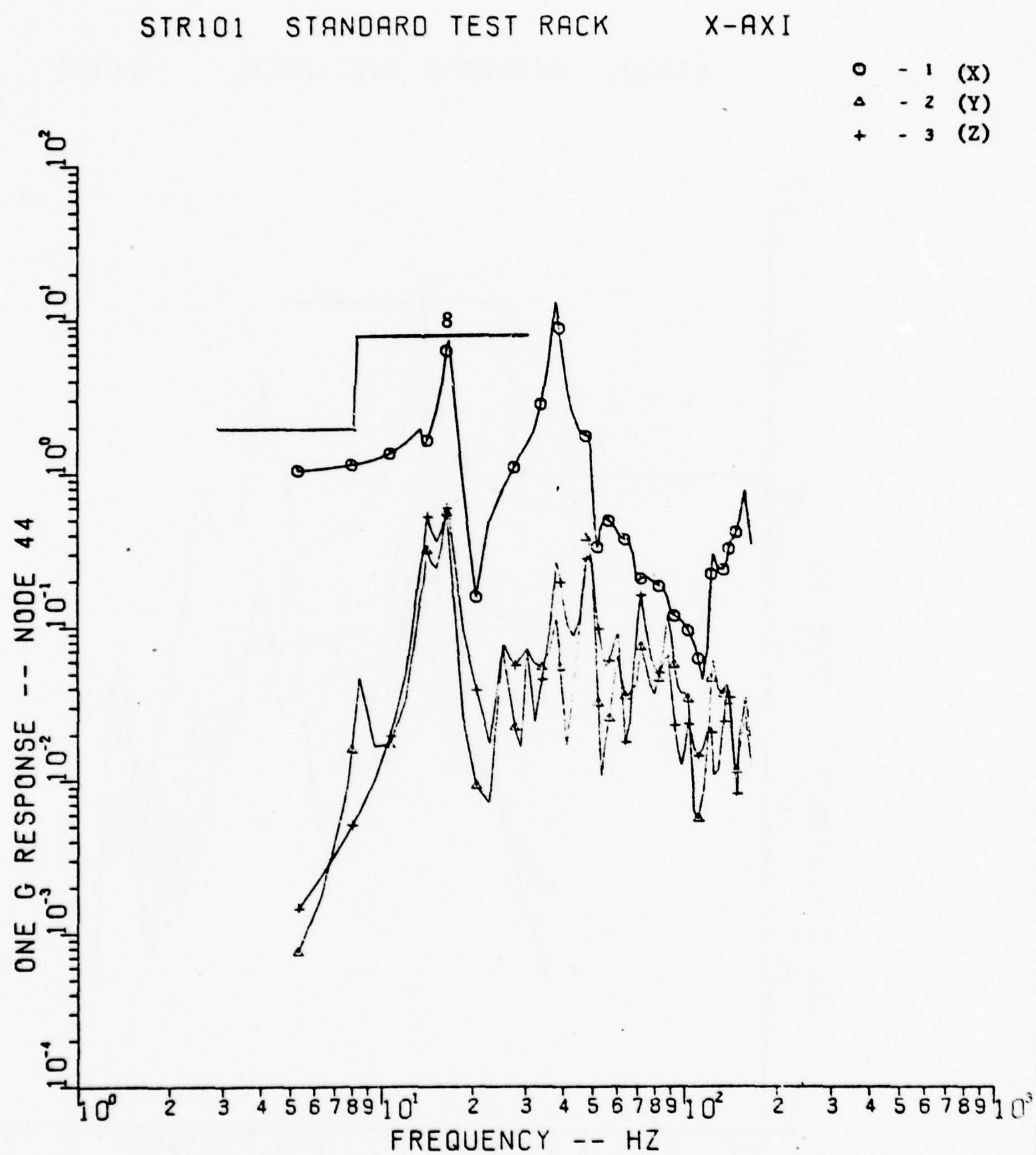


Figure 4.5-4 Quadrapod Payload Frequency Response for 1G X-Axis Acceleration Input

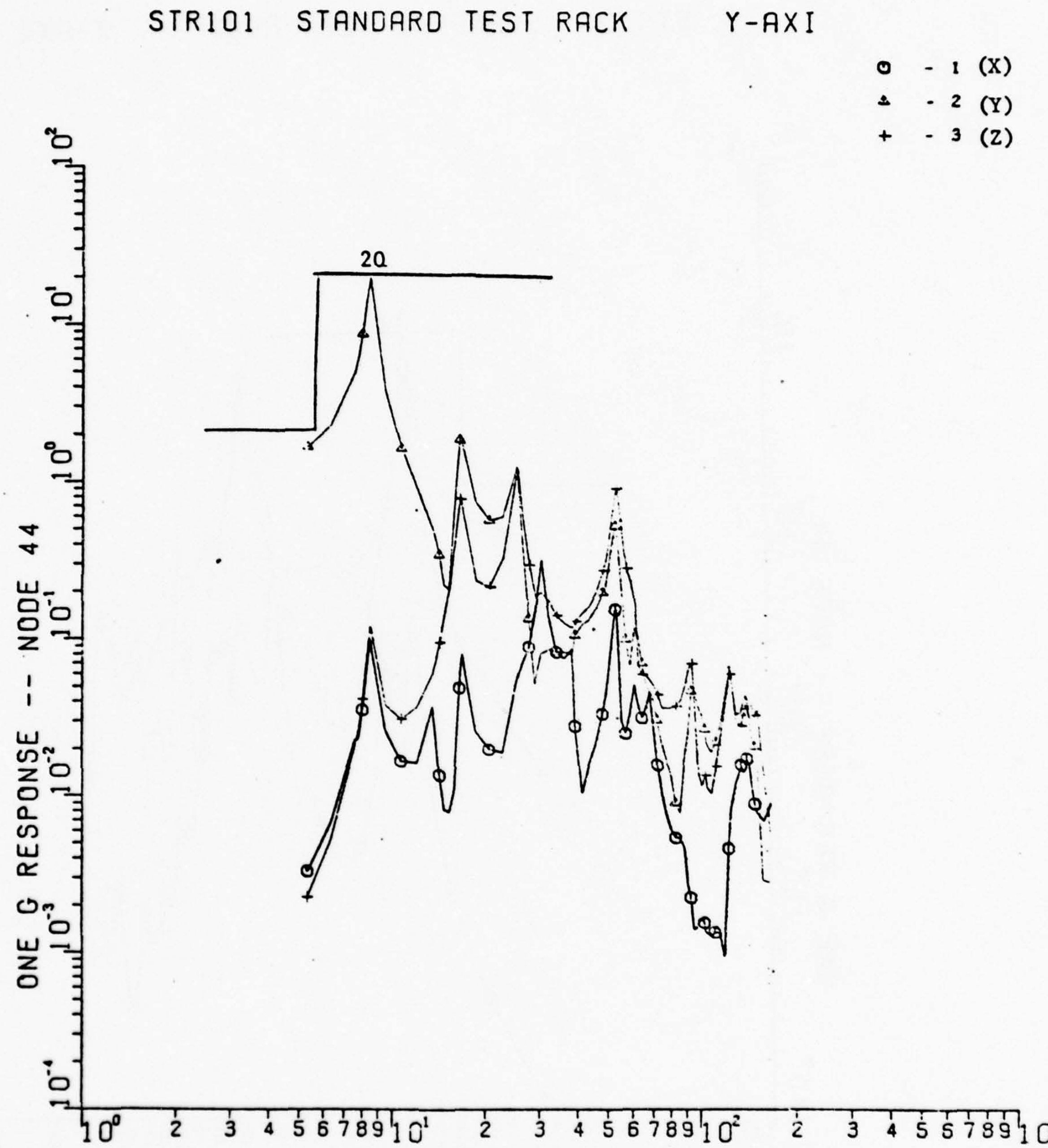


Figure 4.5-5 Quadrapod Payload Frequency Response for 1G X-Axis Acceleration Input

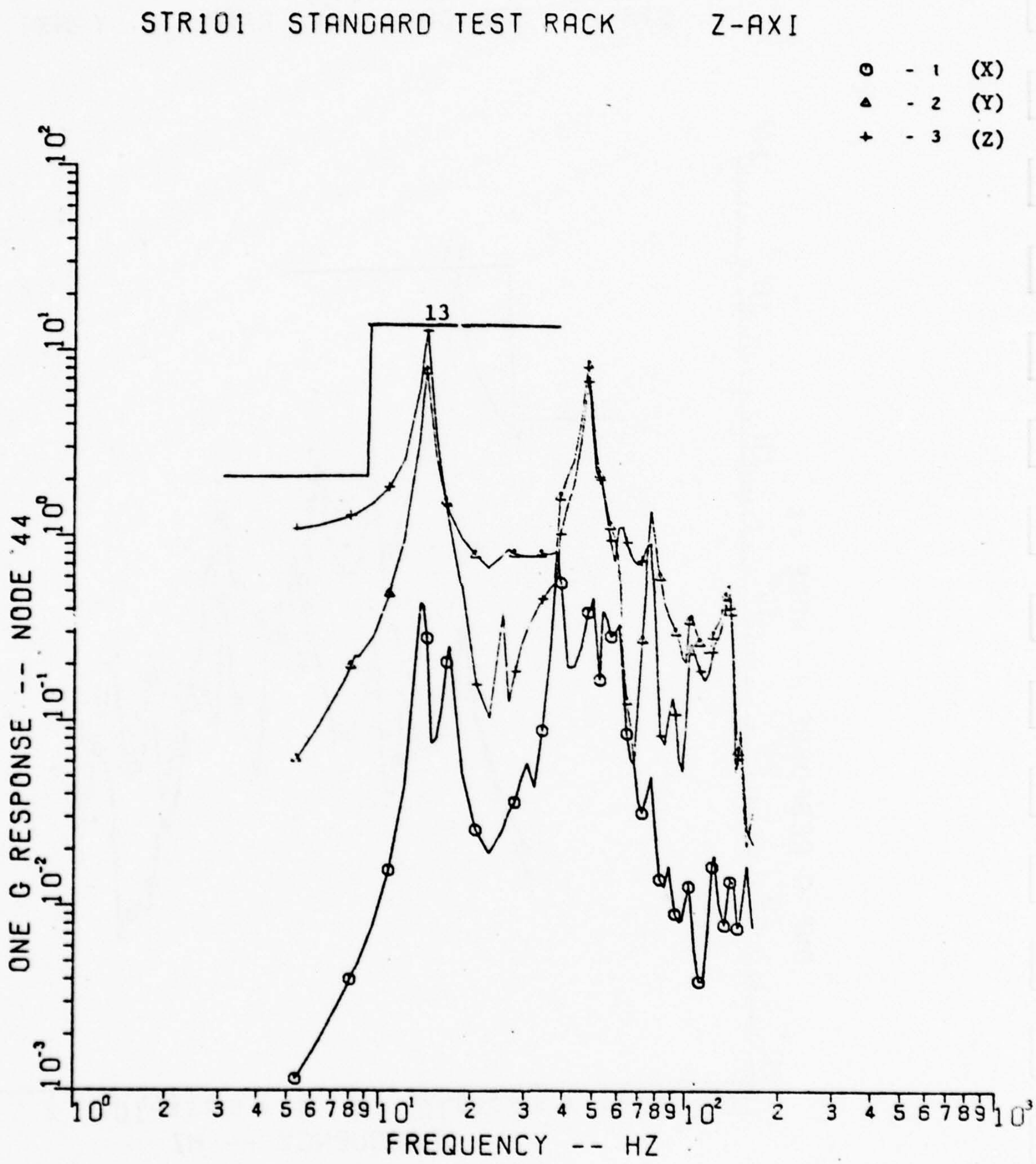


Figure 4.5-6 Quadrapod Payload Frequency Response for 1G Z-Axis Acceleration Input

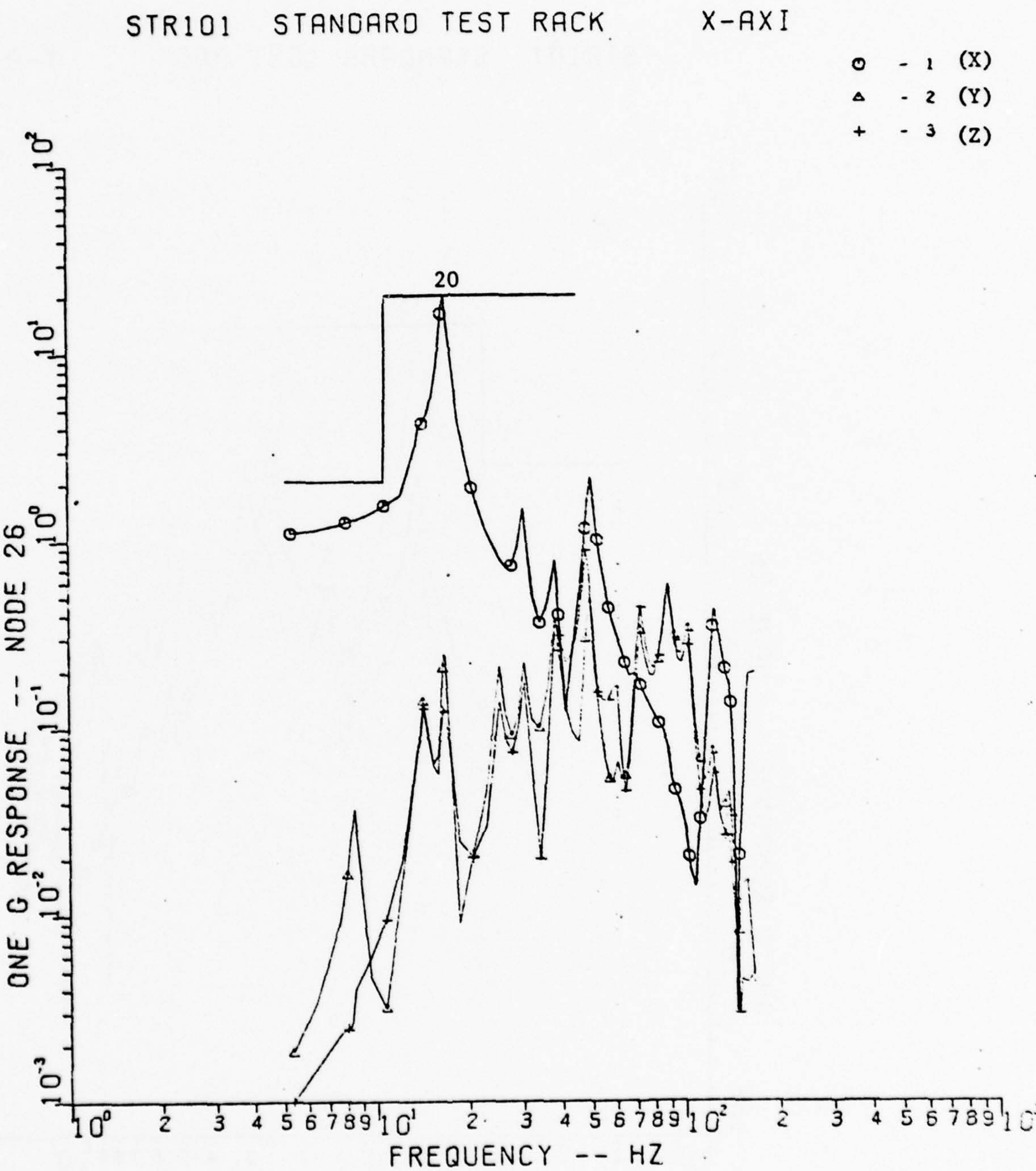


Figure 4.5-7 Equipment Panel Center Payload Frequency Response for 1G X-Axis Acceleration Input

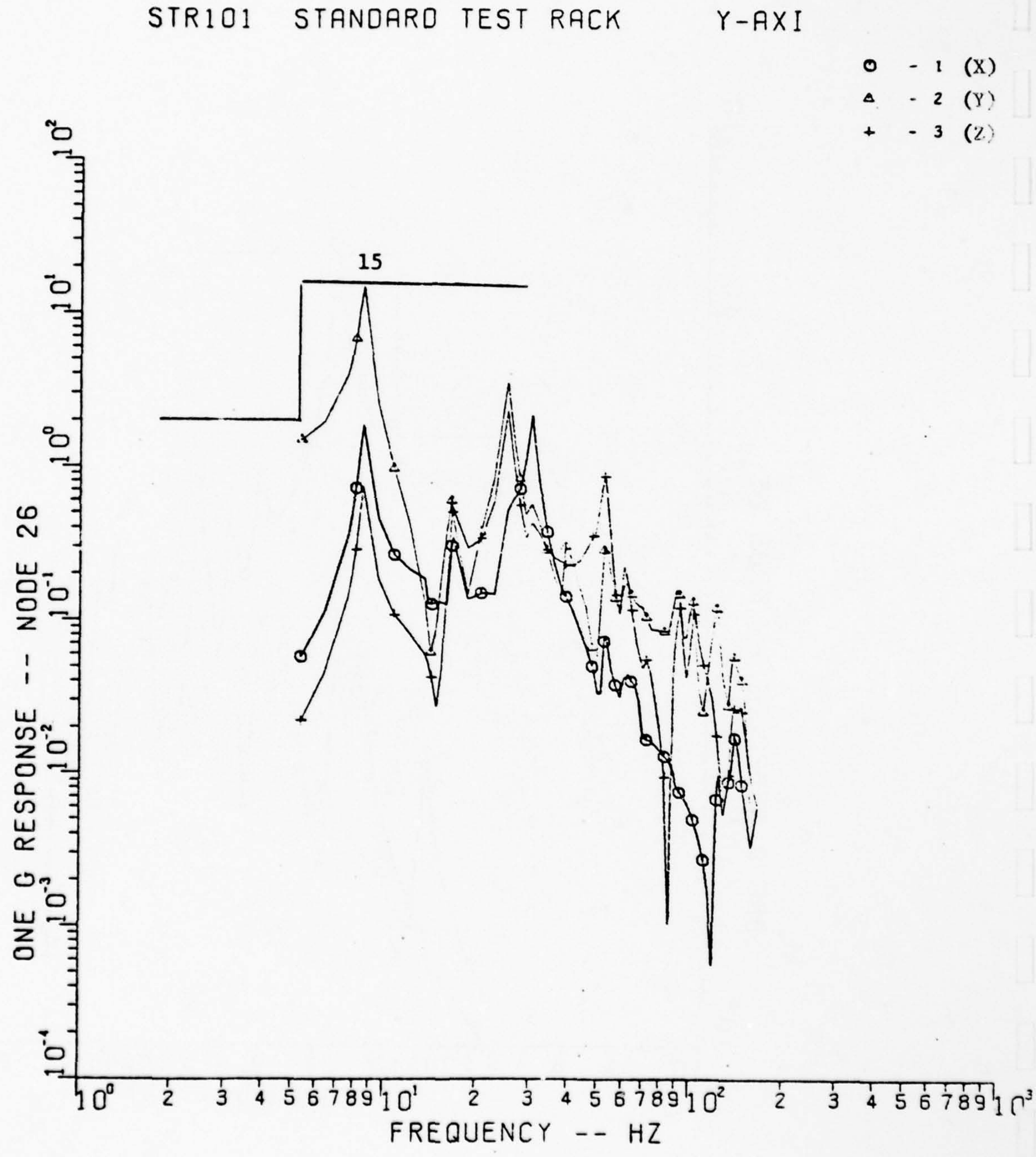


Figure 4.5-8 Equipment Panel Center Payload Frequency Response for 1G Y-Axis Acceleration Input

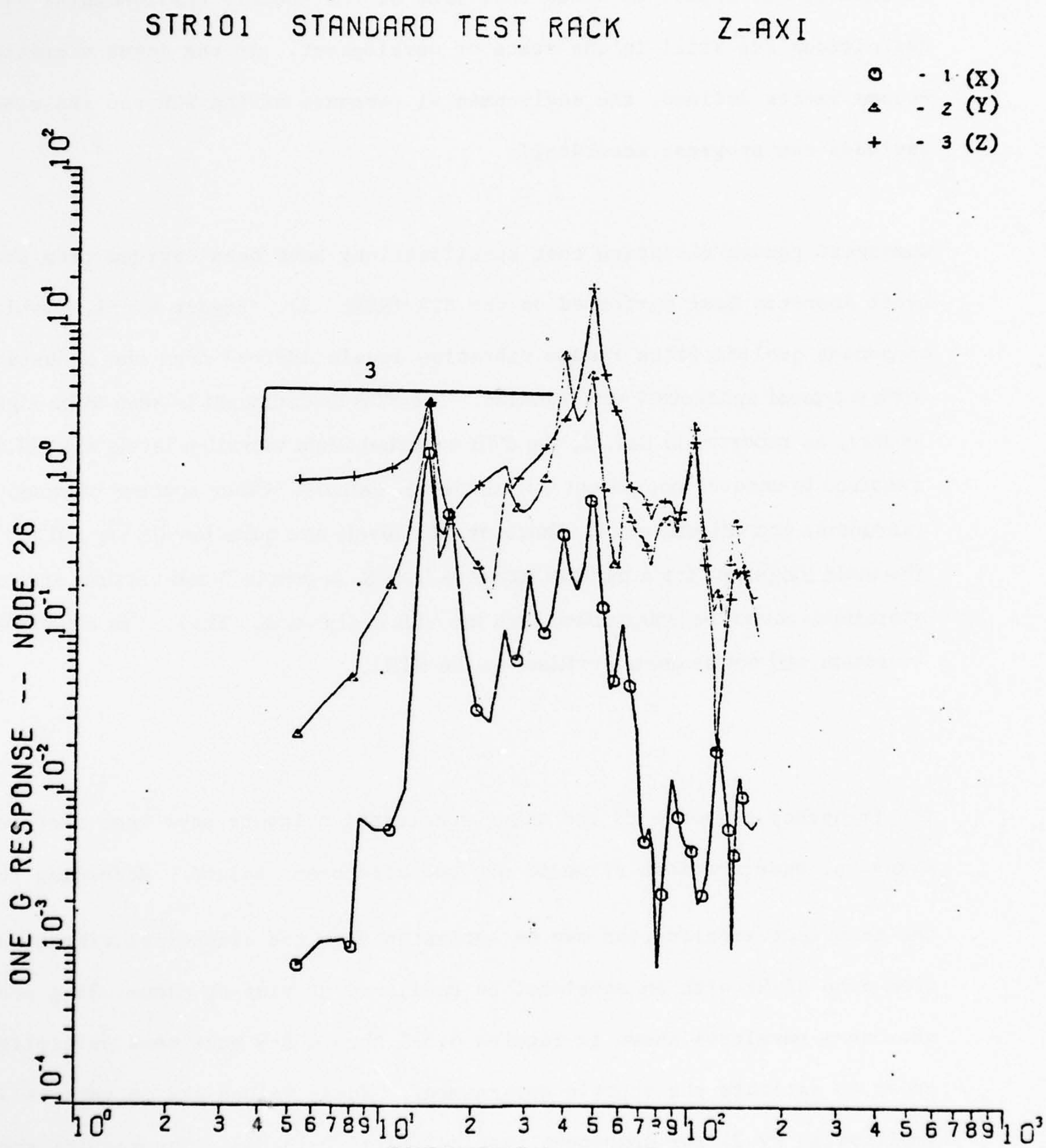


Figure 4.5-9 Equipment Panel Center Payload Frequency Response for 1G Z-Axis Acceleration Input

4.6 Response to Shuttle Environment

This section contains a current assessment of the STR in the shuttle vibration environment. It should be noted that many of the shuttle environmental vibration definitions are still in the state of development. As the input vibration levels become better defined, the environmental response of the STR and its associated payloads can progress accordingly.

Component random vibration test specifications have been derived from the Qualification Level Acoustic Test performed on the STR (REF: 2). Figure 4.6-1, displays the component qualification random vibration levels derived from the acoustic test along with a typical spacecraft specification. The STR environment is seen to be significantly lower. In fact, as reported in Ref. 2, the STR expected flight vibration levels are below those required to uncover component workmanship, defects. Other sources of random vibration (aeronoise and lift-off) exist. However, the levels are quite low (below .01 g^2/Hz) at the main longerons for a payload bay (see Ref. 3 Appendix I) and vertical and longitudinal vibrations cannot be transmitted thru the STR keel fitting. Thus, it is concluded that random vibration will not be design critical on the STR.

The frequency response to the one-g acceleration inputs have been used to estimate the transient accelerations at major payload attachment points. According to Ref. 4 the transient acceleration may be estimated from the sinusoidal vibration environment from 5 to 35 Hz with an acceleration amplitude of plus or minus .25 g peak. Thus, the one-g envelopes shown in Figures 4.5-1 thru 4.5-9 have been multiplied by .25 in order to estimate the shuttle environment. These values are in turn raised by 6 dB (mulitplied by 2) for component testing (MIL-STD-1540A). The results are summarized in Table 4.6-1. The maximum expected accelerations are below the 20 g minimum specified in MIL-STD-1540A, and evidently this minimum will govern the test specifications.

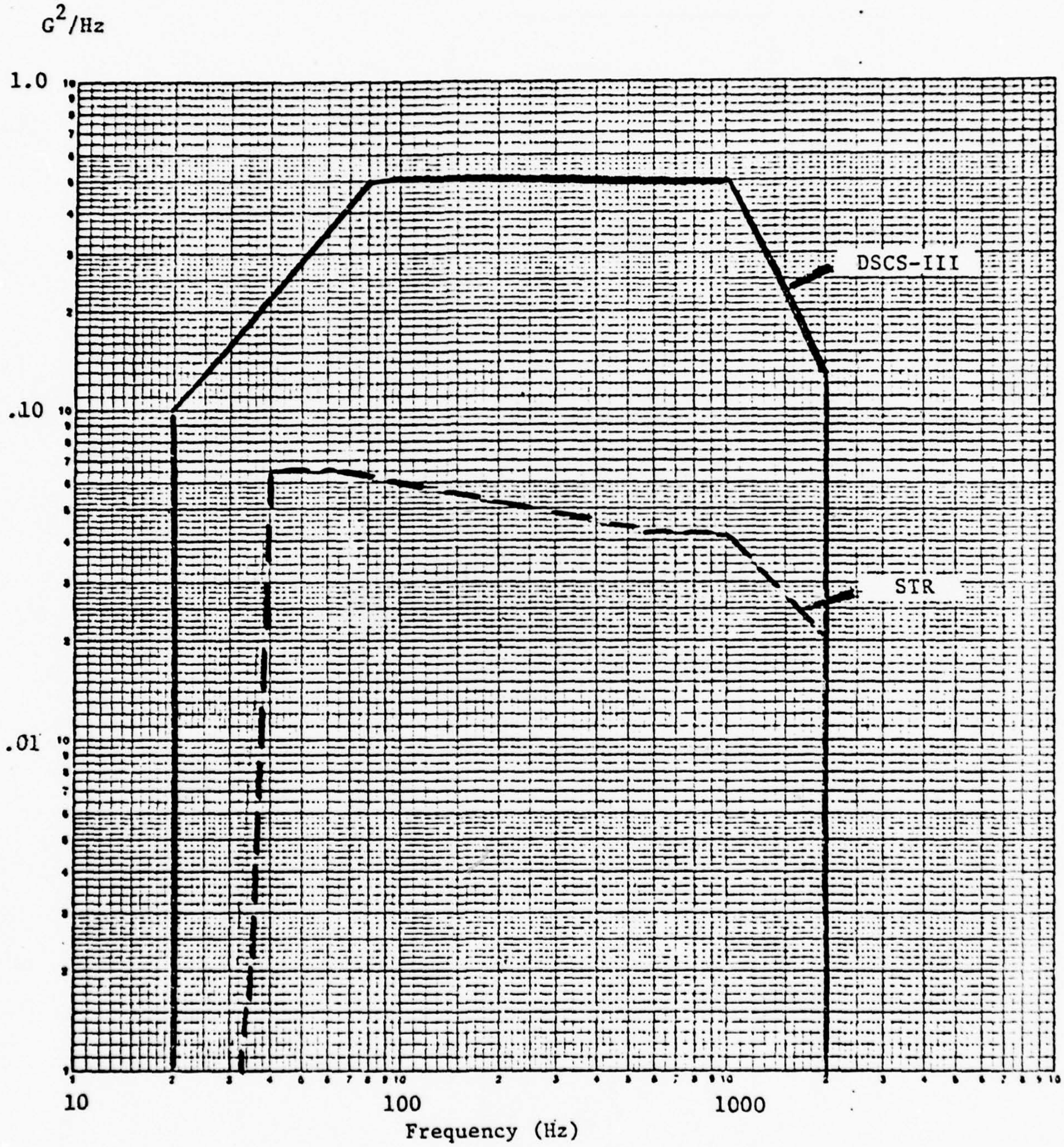


Figure 4.6-1 STR Component Random Vibration Qualification Test Specifications (Derived from Acoustic Test)

Table 4.6-1 Estimate of Payload Transient Vibration Environment

Component	Peak Acceleration 0-35 Hz, One-G Input	Peak Acceleration 1/4 G Input (Est. Transient)	Peak Acceleration 1/4 G Input +6 dB For Component Testing
Points Payload (800#) (Node 53)	24 g	6	12
Bridge Payload (796#) (Node 44)	20 g	5	10
Equipment Panel Center (Node 26, 89#)	20g	5	10

MIL-STD-1540A
Specifies 20g
Minimum

Since the results are highly dependent on modal damping, it is recommended that an STR modal test be performed to update the values of damping used in the one-g analysis. In this light, it would also be beneficial to investigate damping treatments for major payload attach points.

The transient loading of the STR will vary to some extent depending on its position within the STS payload bay. Analyses of two Global Positioning satellites each attached to Inertial Upper Stage boosters is presented in TR-76-212 Vol. VI, Section 3.0. These analytical results show that the forward satellite experiences large acceleration due to pitching. Therefore, it would be highly desirable to perform a coupled STR/STS analysis for a forward location of the STR.

4.7 Design of Damped Structure

The General Electric Space Division has been pursuing viscoealstic damping material development and application for over eight years. Integrally damped designs have been successfully implemented in circuit boards, a spherical gimbal, acoustic enclosures, and in a variety of other applications dicussed in Reference 5. The design and construction of an integrally damped component panel was undertaken during the STR program. It was installed on the STR and loaded with dummy batteries for the acoustic test. Results of this test and a description of the analysis leading to the design of the damped panel is contained in Reference 2. The damped panel design has not been incorporated in the current NASTRAN model.

It is felt that major payloads mounted to the bridge (POINTS and quadrapods) represent another area where damping teatment can be incorporated to attenuate dynamic response. It is thus recommended that an integrally damped bridge design be investigated. The natural modes and frequency response analyses which have been performed will be of service to this design effort, in that they identify the type of motion to be attenuated.

5.0 REFERENCES

1.0 Page, R. "NASTRAN Computer Model of the STR", General Electric - Space Division, PIR 1R43,STR-690, August 1978.

2.0 Mirandy, L., "Standard Test Rack Acoustic Test Report", GE Document No. 78SDS4246, September 29, 1978.

3.0 NASA-JSC-ICD-2-19001, "Space Shuttle Interface Control Document, Level 11".

4.0 NASA-JSC-07700, Volume 14, Revision E, "Space Shuttle System Payload Accommodations."

5.0 Medaglia, J., and Stahle, C., "SMRD Damping Applications", AFFDL-TM-78-78-FBA, February, 1978.

APPENDIX A

STR COMPUTER MODEL

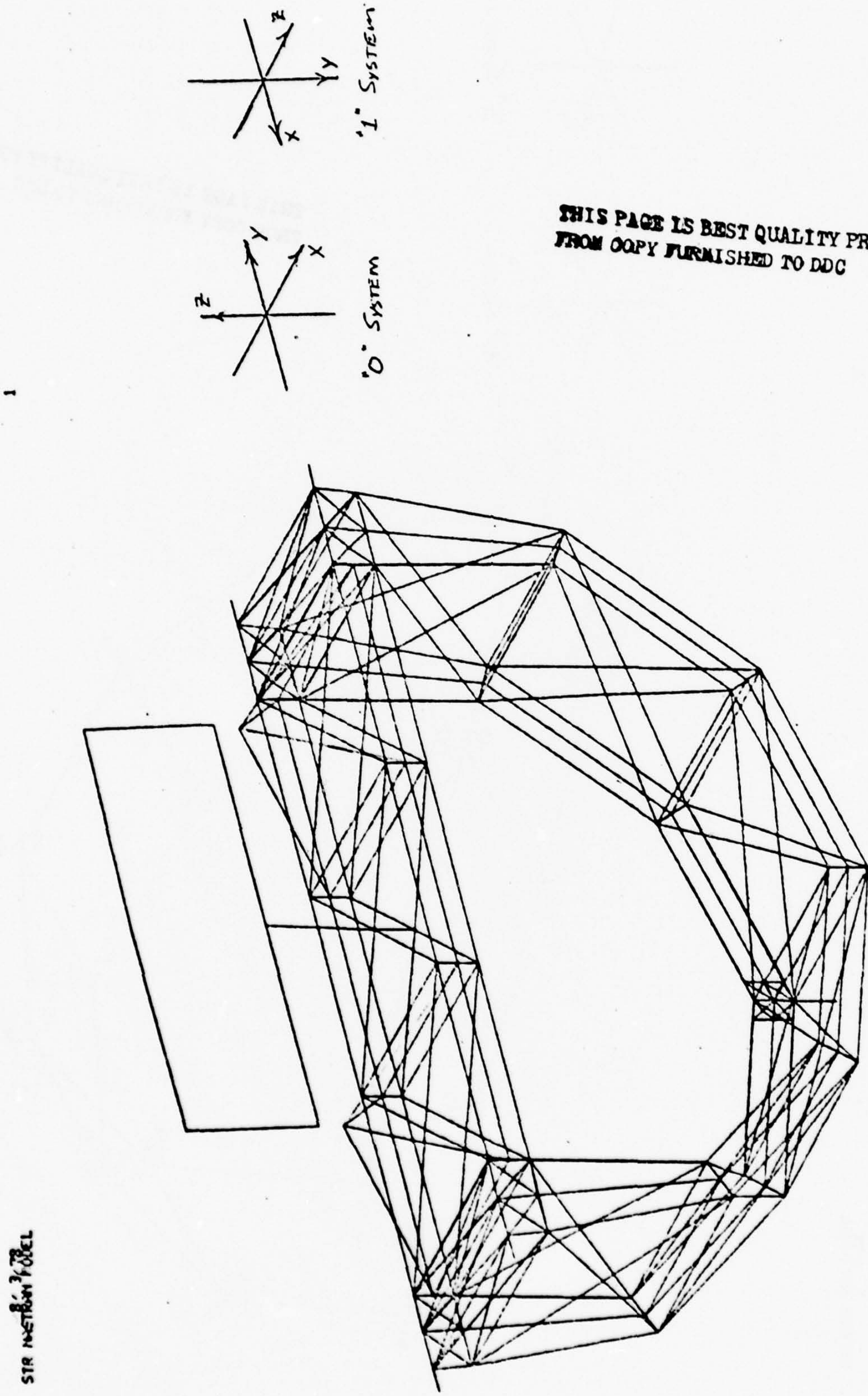
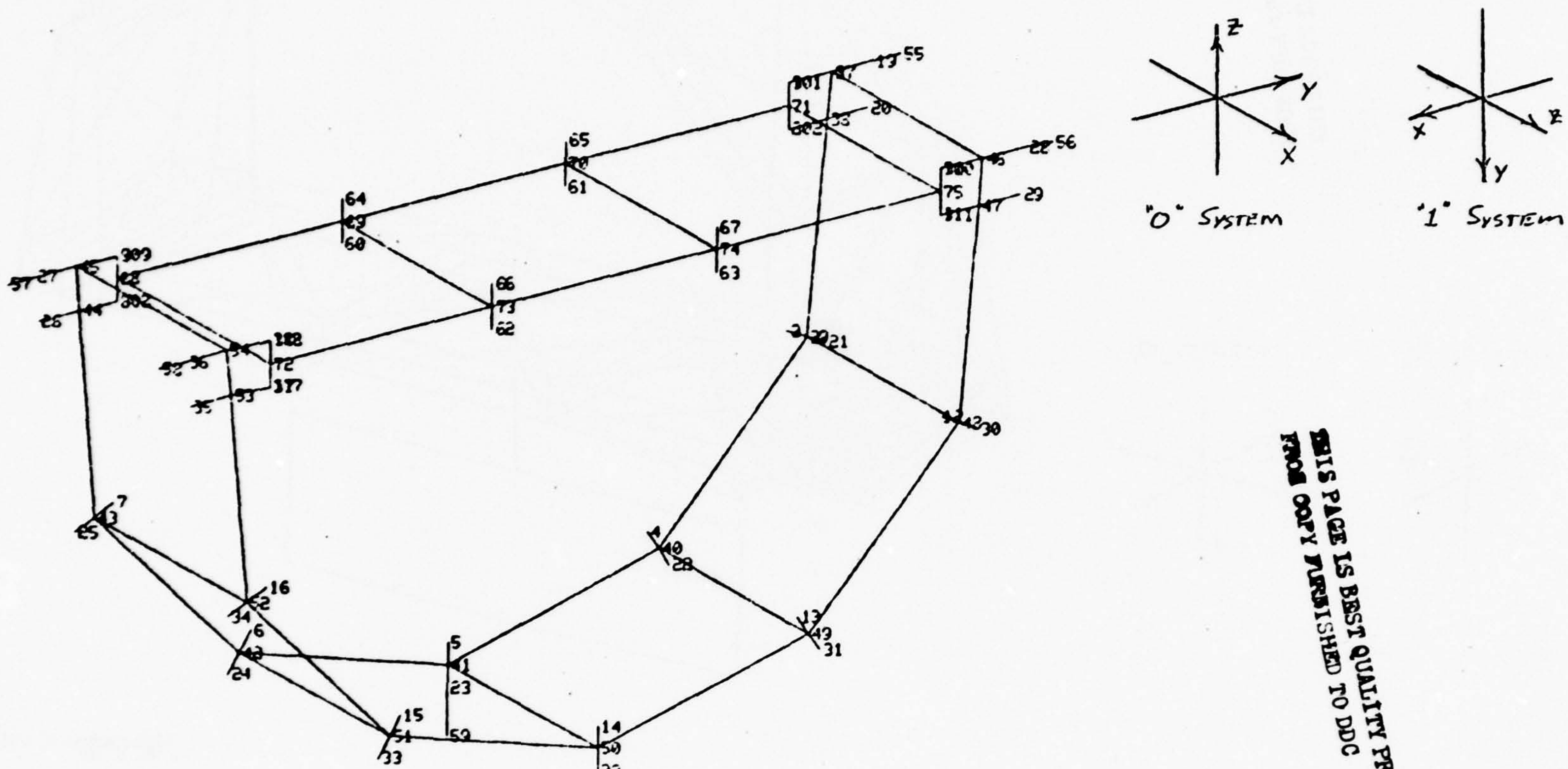


FIGURE A-1

SHUTTLE TEST RACK PLOTTING RUN

INITIAL STR MODEL 8-3-78

2



SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-2

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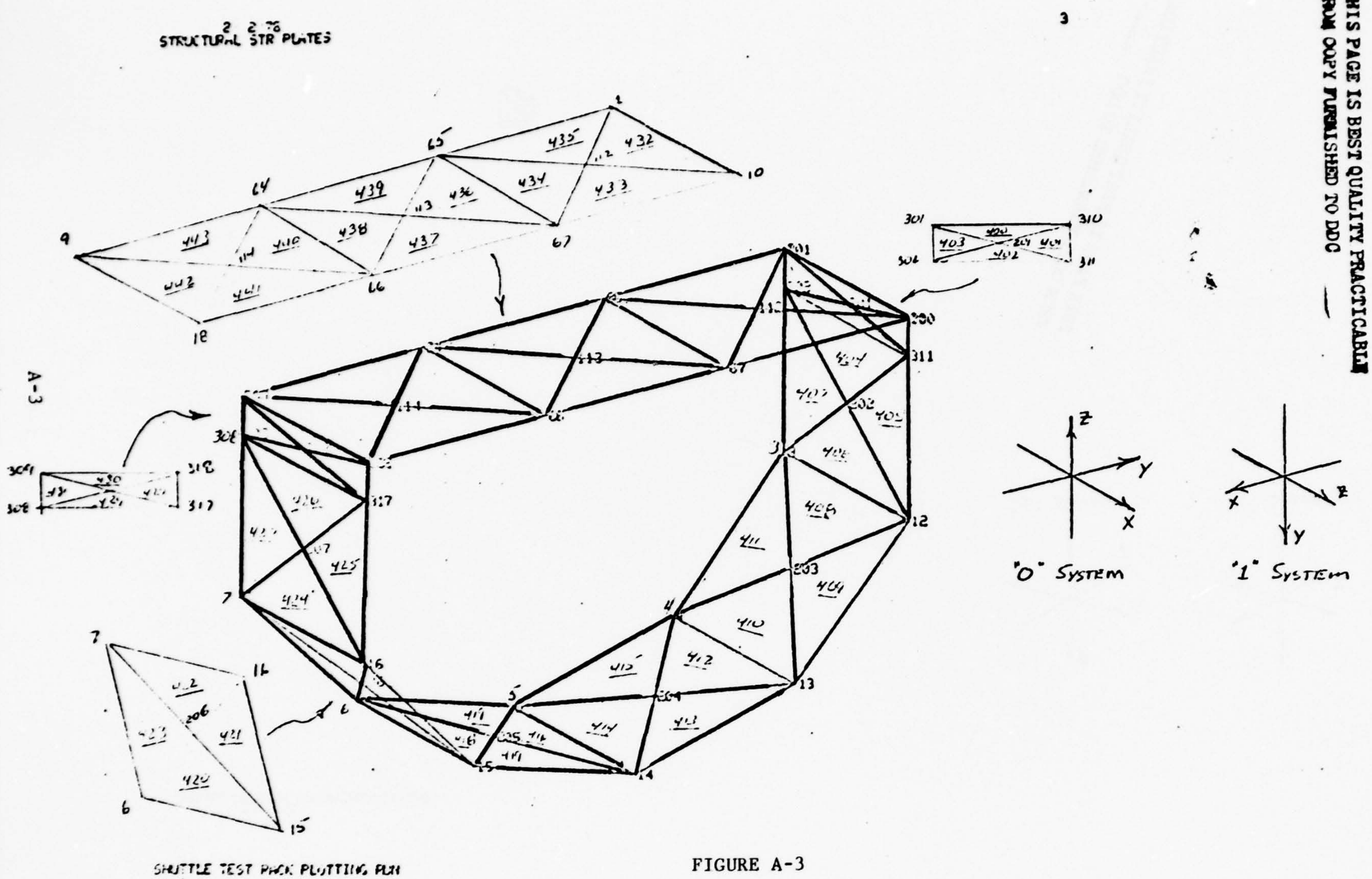
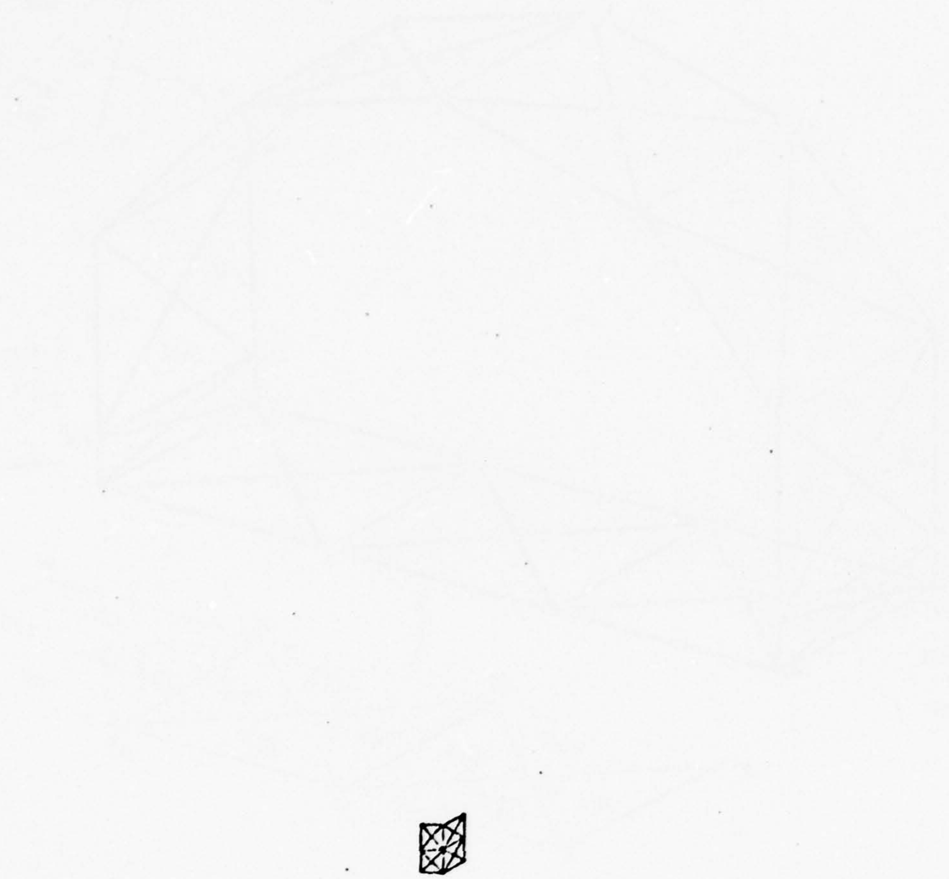
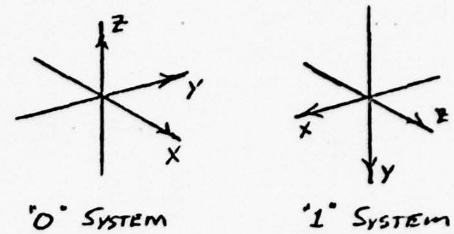


FIGURE A-3

DETAIL OF KEEL TRUNNION FITTING 8/2/78





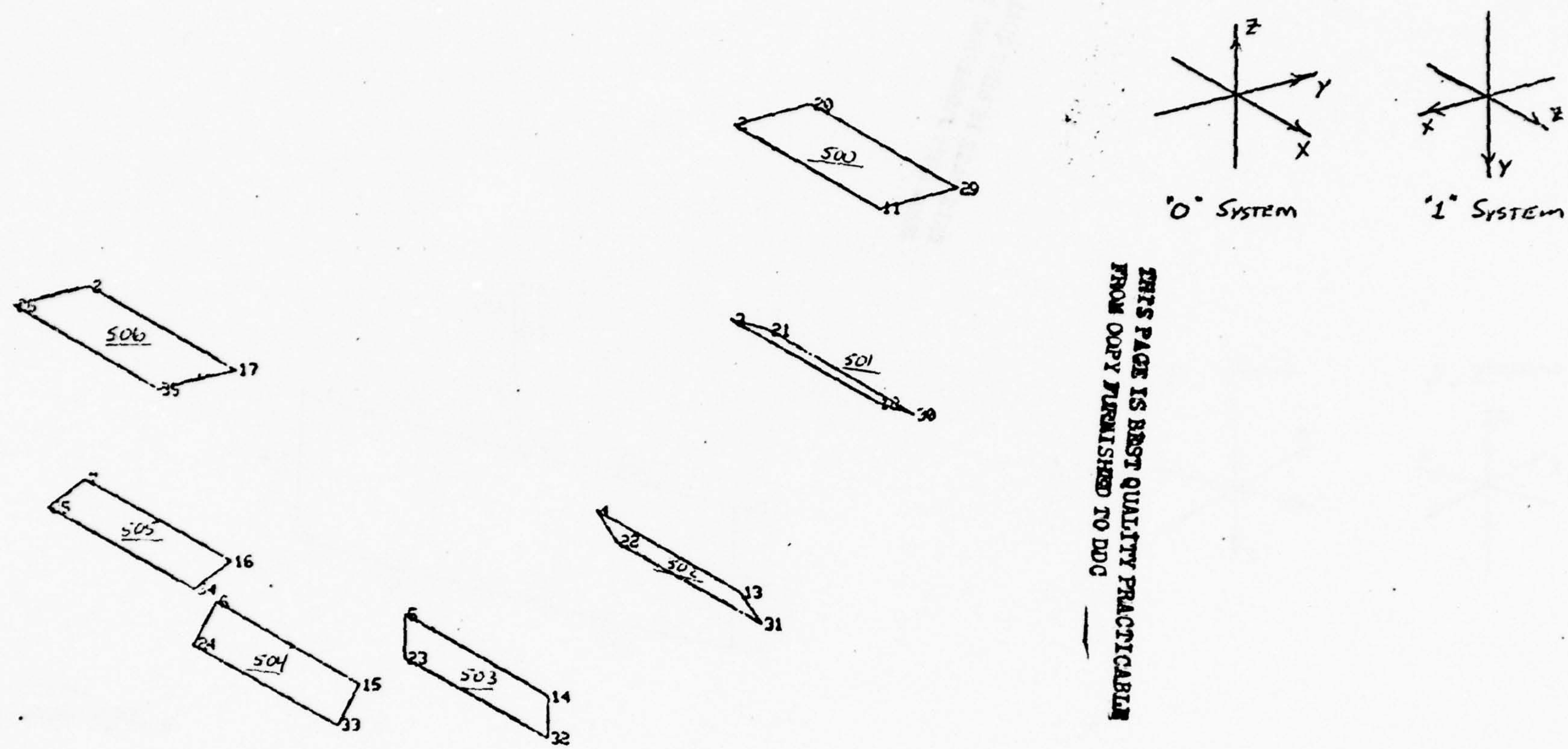
SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-4

INTERNAL PLATES OF STR 8-2-78

CQUAD4 S

5



SHUTTLE TEST PACK PLOTTING RUN

FIGURE A-5

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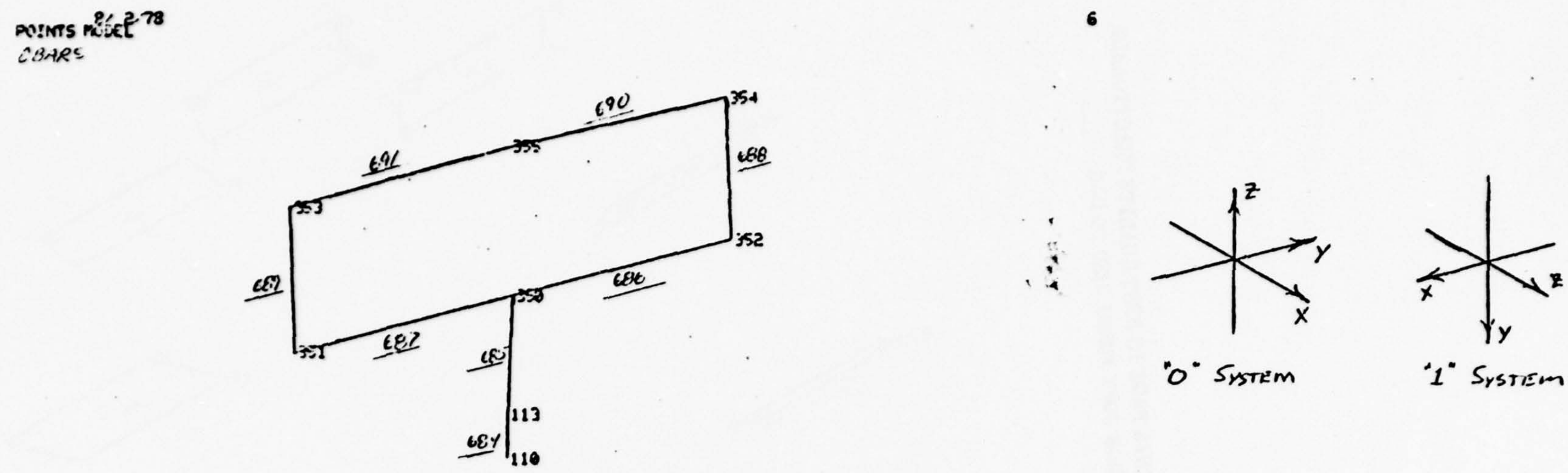


SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-6

LOAD CARRYING PANELS OF STP

8/ 2/78

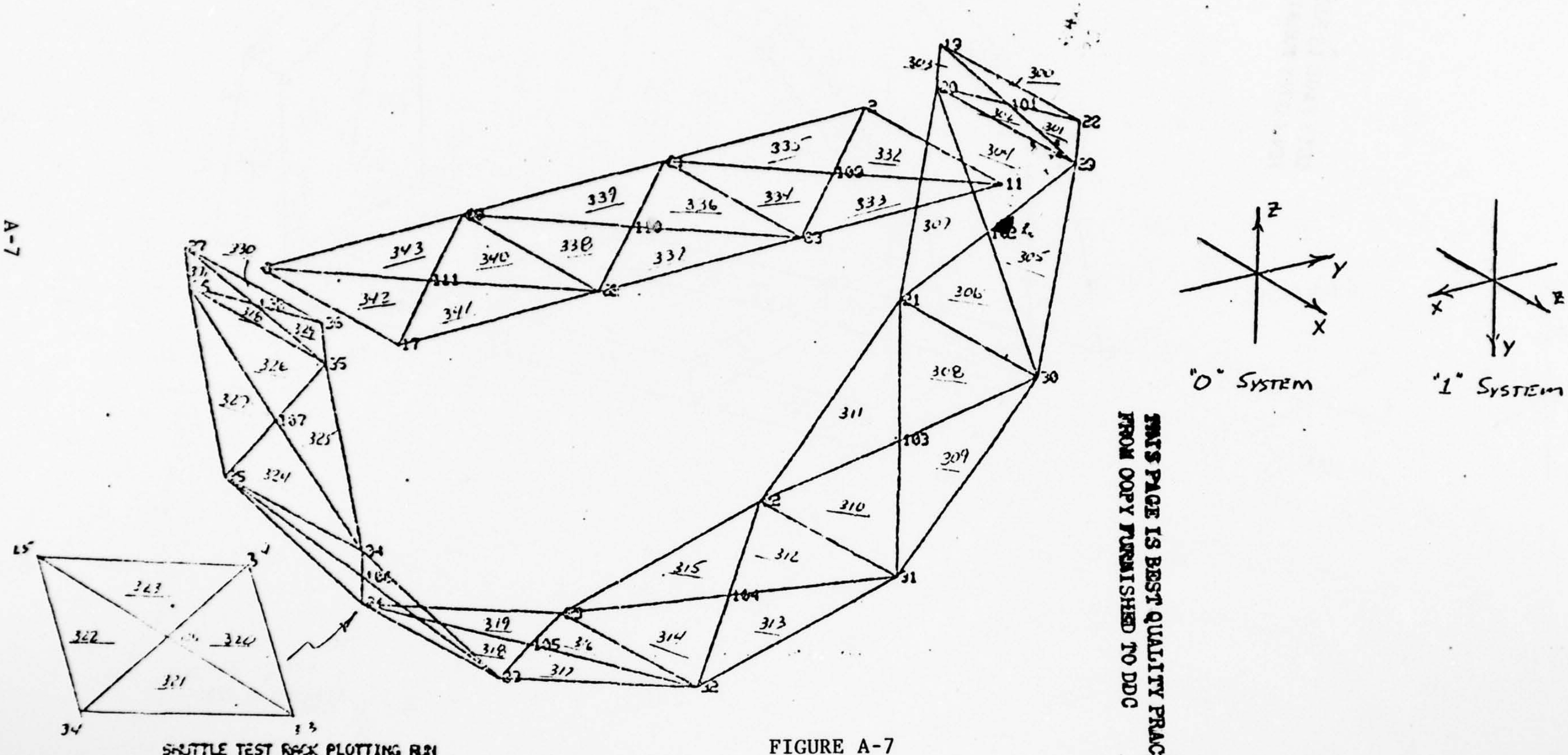
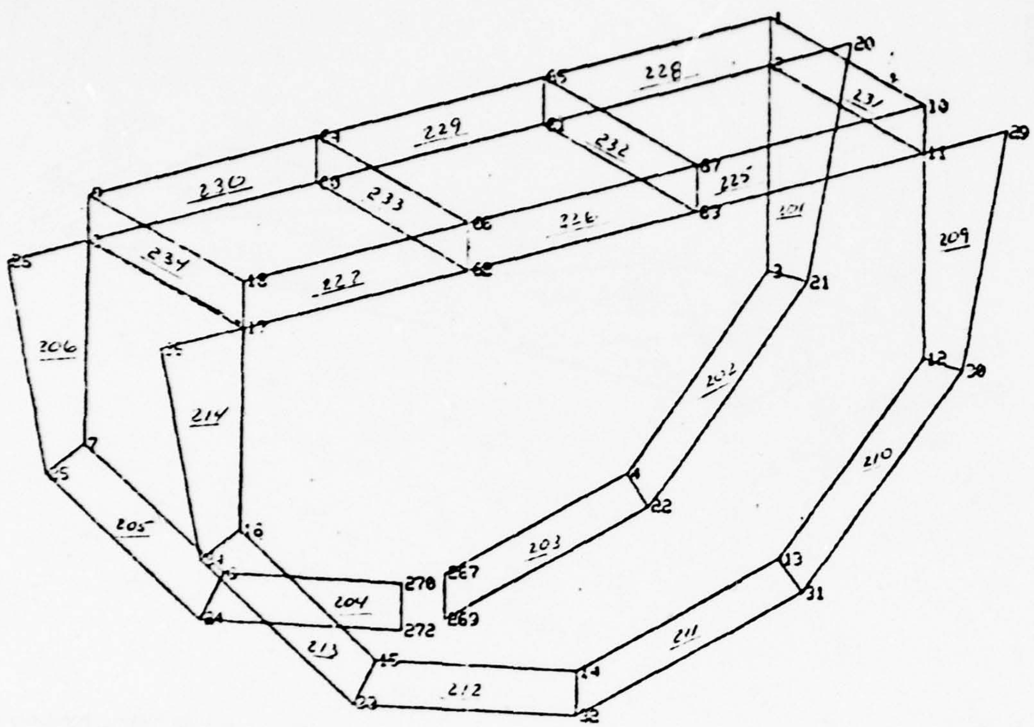
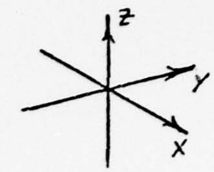


FIGURE A-7

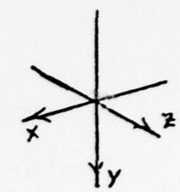
8/2/78
LEGS OF CHANNELS
+ Bridge Plates

3





"O" System

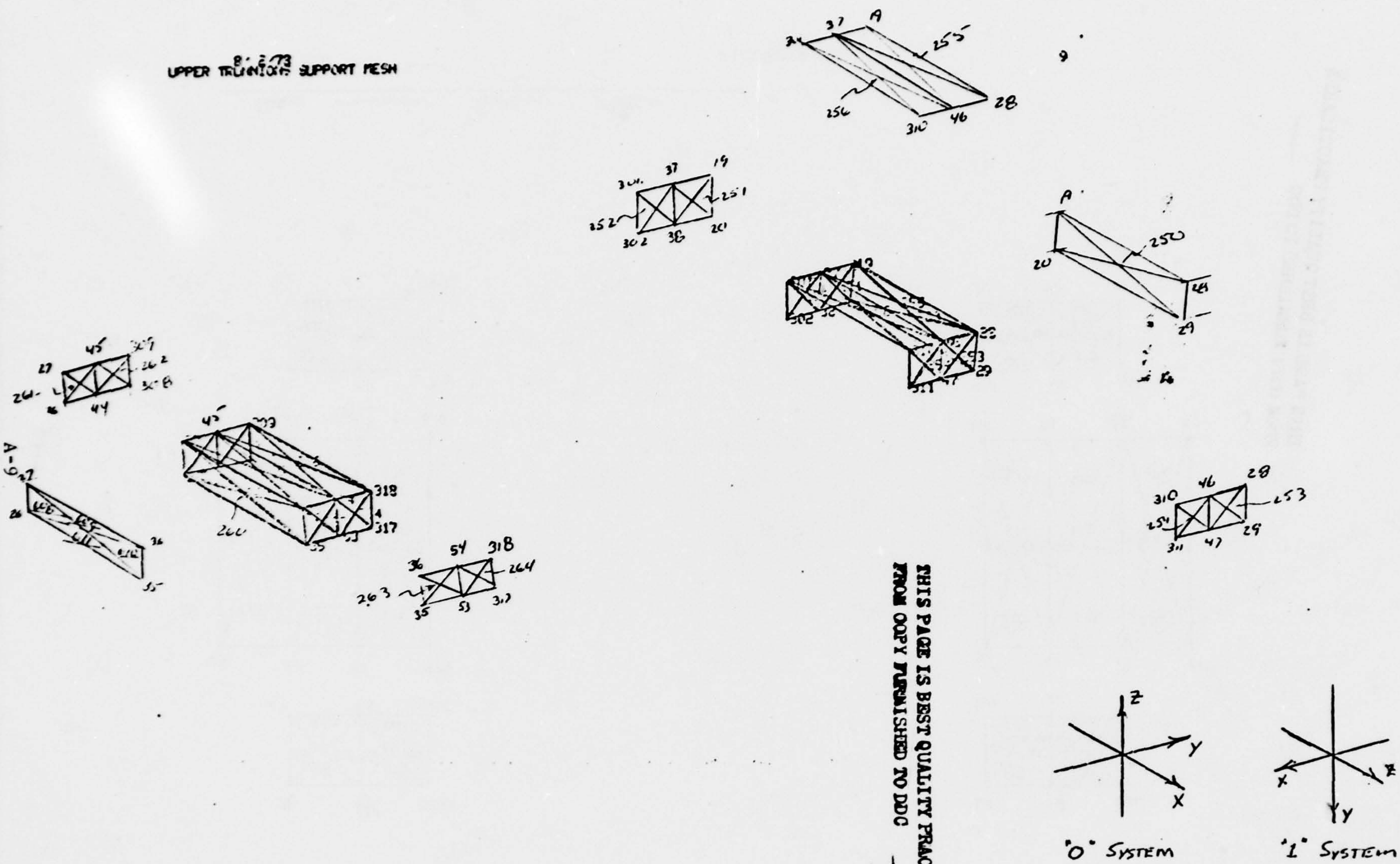


"1" System

SHUTTLE TEST PACK PLOTTING RUN

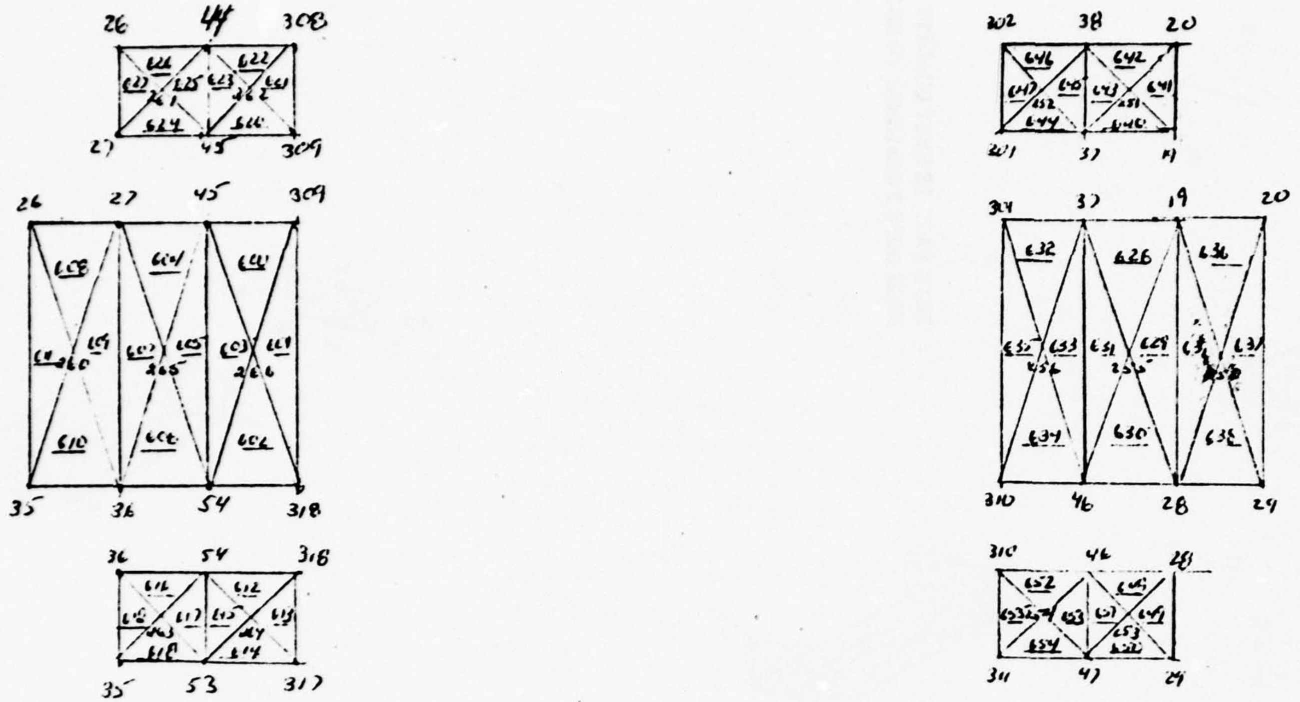
FIGURE A-8

8-2-73
UPPER TRUNNION SUPPORT MESH



SHUTTLE TEST PACK PLOTTING RUN

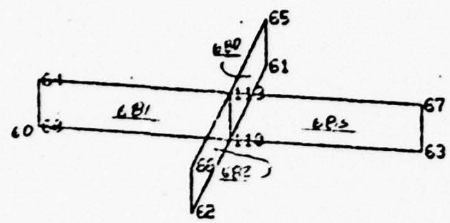
FIGURE A-9

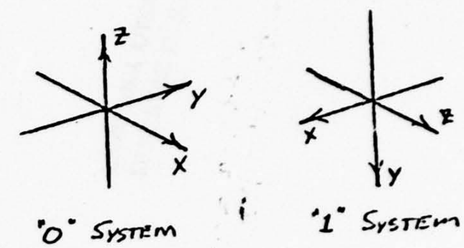


UPPER TRUNNION SUPPORT MESH

FIGURE A-10

POINTS PLATE SYSTEM
CQUAD4 S



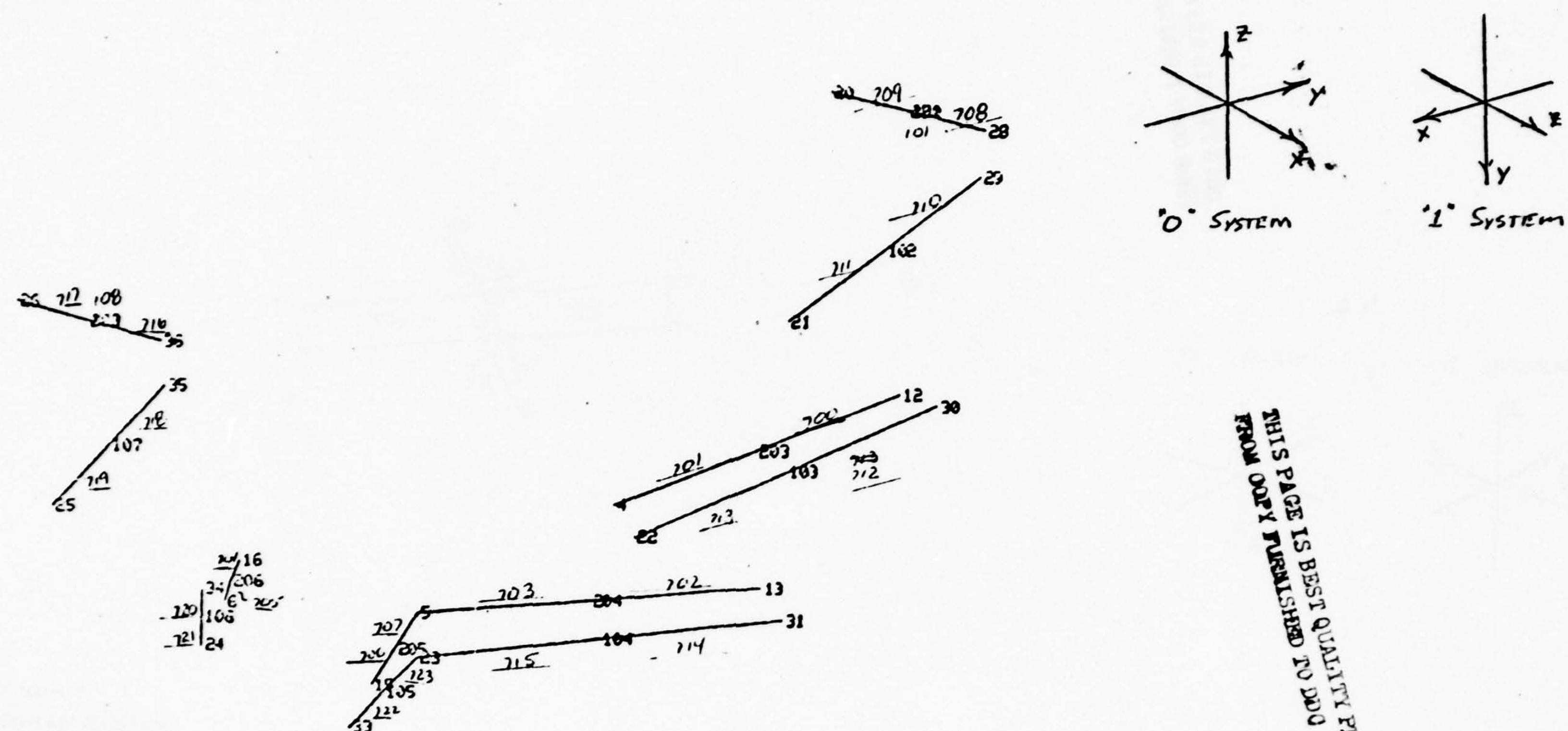


SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-11

PLATE STIFFNESS RODS 8-2-78

11

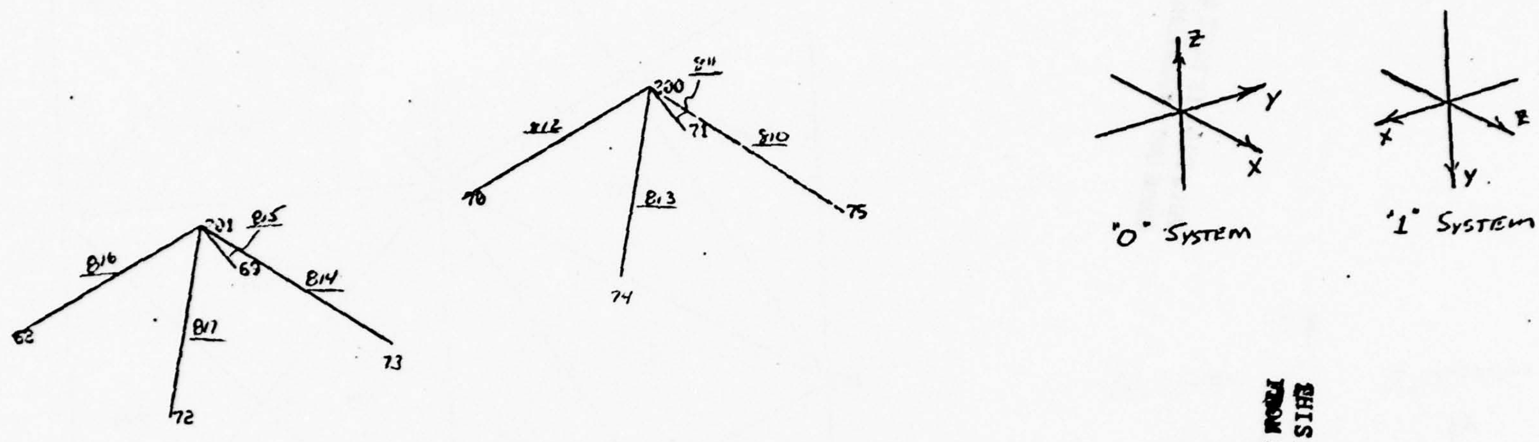


SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-12

12

BRIDGE LOADING POINTS 8-2-78
CONRODS

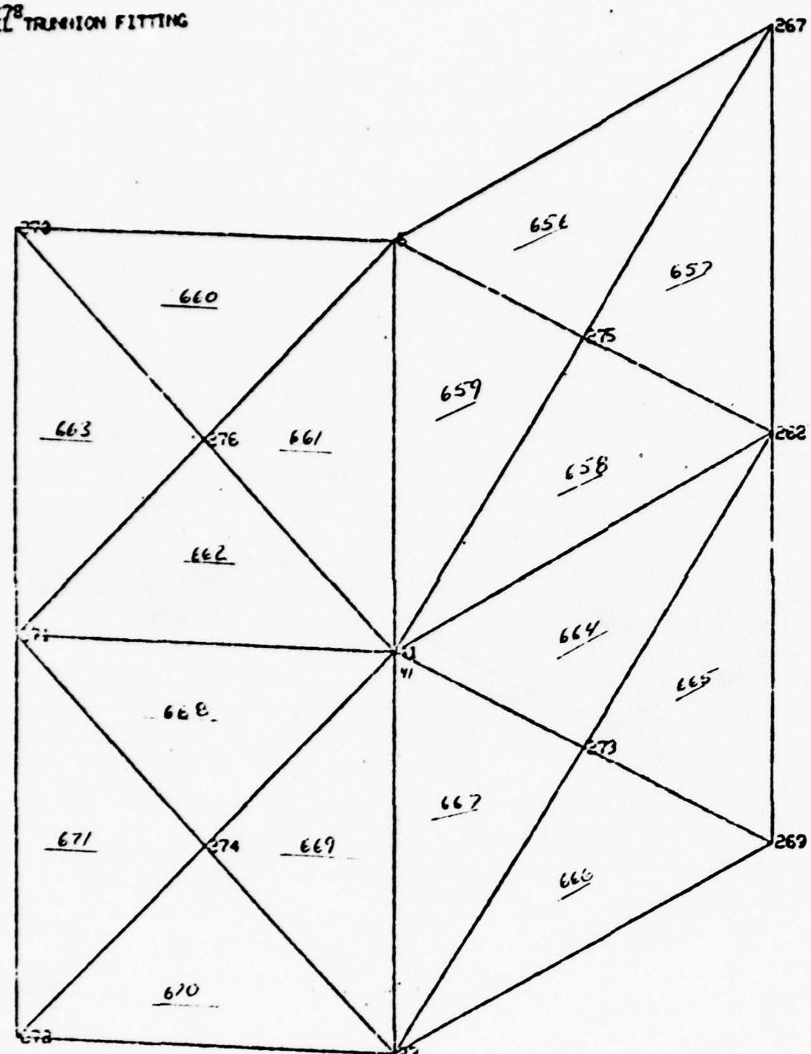


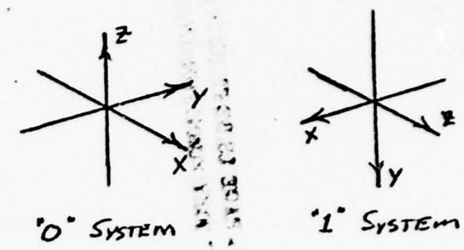
SHUTTLE TEST PACK PLOTTING RUN

FIGURE A-13

DETAIL OF KEEL TRUNNION FITTING 8/2/78

13





SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-14

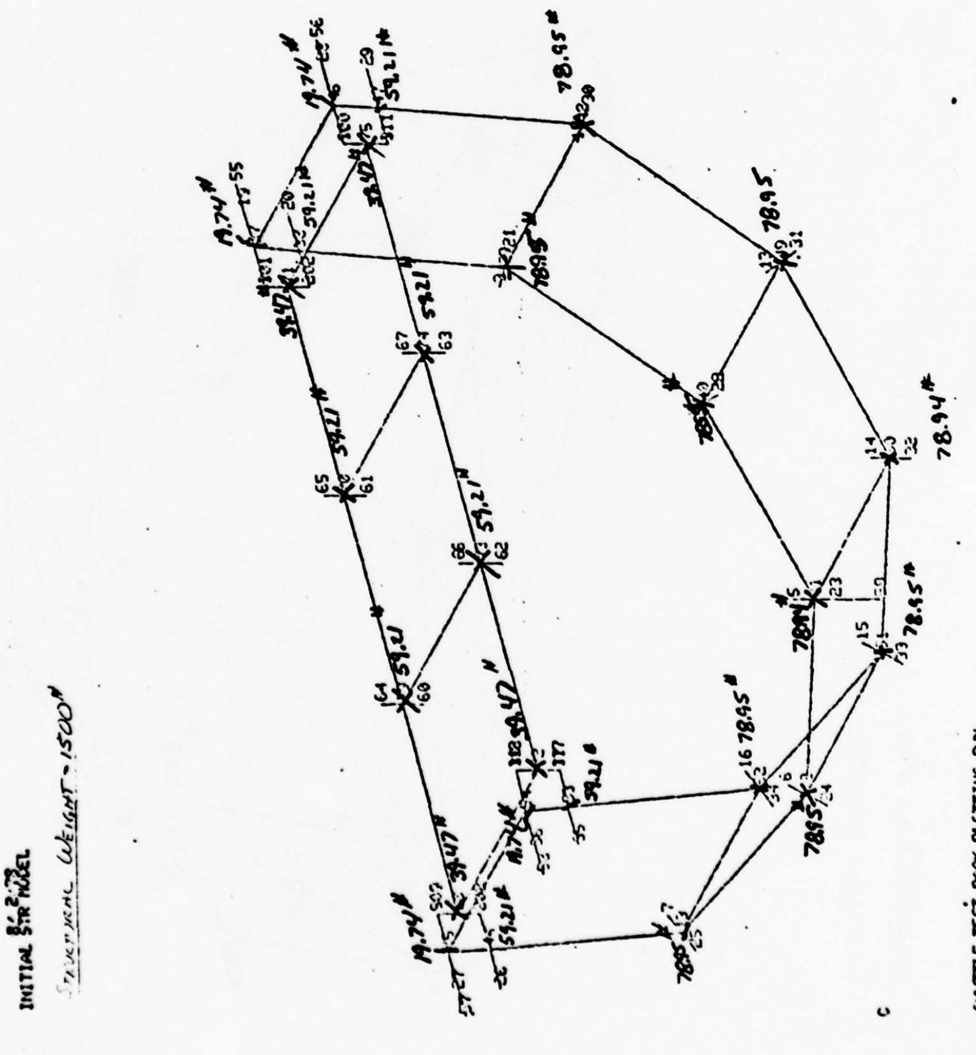
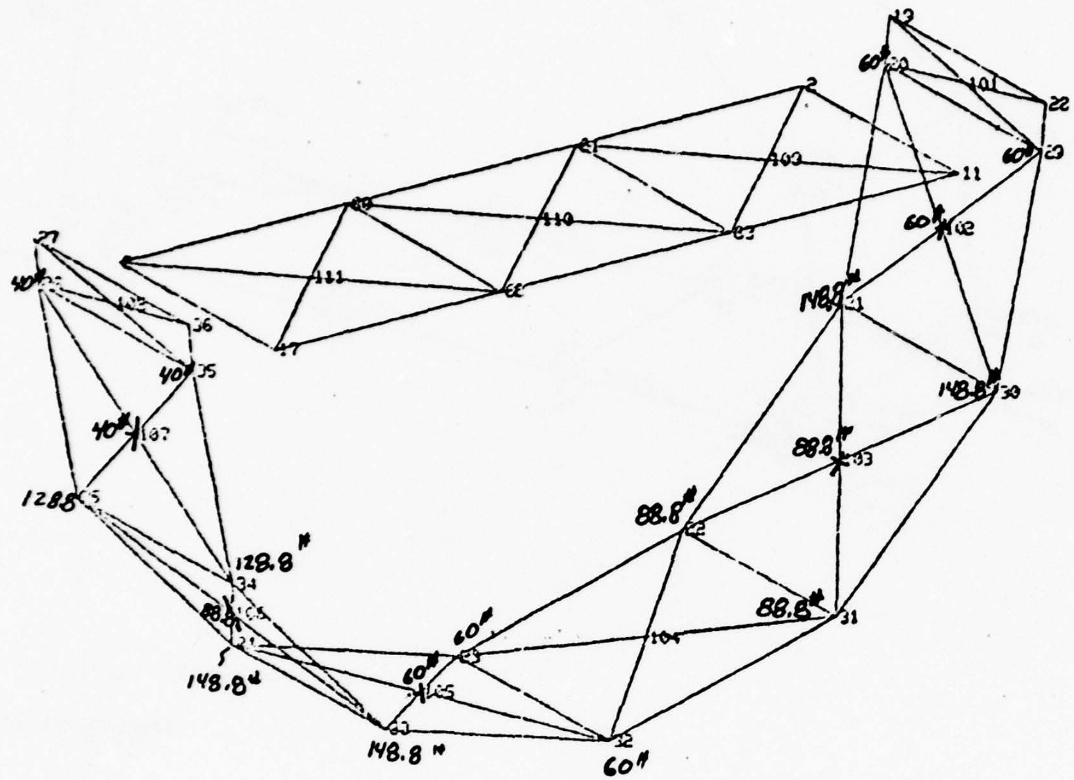

INITIAL STR MODEL
STRUCTURAL WEIGHT - 1500#
SHUTTLE TEST RACK PLOTTING RUN
78.95#
59.21#
59.47#
19.74#
78.94#

FIGURE A-15

8/2/79
LOAD CARRYING PANELS OF STP

SUBSYSTEM WEIGHT = 1687.6#

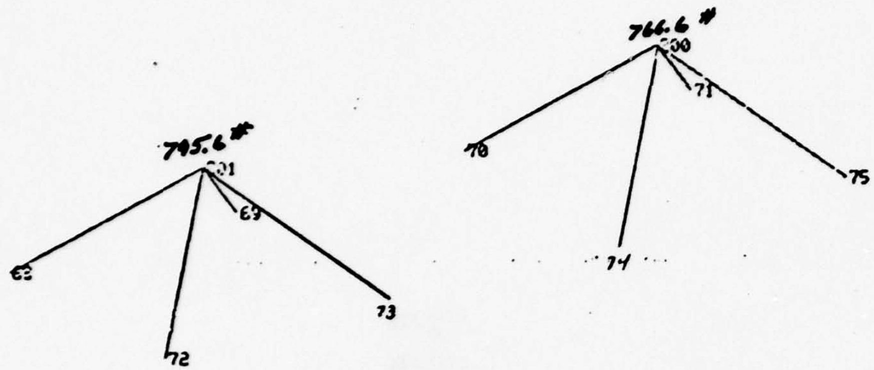


SHUTTLE TEST RACK PLOTTING RUN

FIGURE A-16

12

BRIDGE LOADING POINTS 8-2-78
EXTRA PAYLOAD WEIGHT = 1562.2 #



SHUTTLE TEST PACK PLOTTING RUN

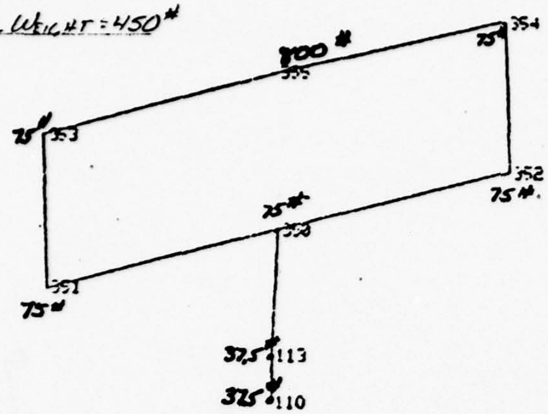
FIGURE A-17

POINTS MODEL 8/2/78

Points Payload Weight = 800#

Points Structure Weight = 450#

6



SHUTTLE TEST PACK PLOTTING RUN

FIGURE A-18

APPENDIX B

STRESS ANALYSIS OF KEY MEMBERS OF STR

BY R. Page	GENERAL ELECTRIC	PAGE
CK.		MODEL
DATE REV.		REPORT STR

TABLE OF CONTENTS

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CK.		MODEL 77
DATE REV.		REPORT

THE TEST RACK IS MADE FROM 6061-T6 ALUMINUM. THE MATERIAL PROPERTIES WERE TAKEN FROM MILHDBK 5B.

THE FORCES AND STRESSES USED IN THE FOLLOWING COMPUTATIONS WERE OBTAINED FROM THE NASTRAN COMPUTER OUTPUT.

THE FOLLOWING IS A LIST OF REFERENCES USED:

1.) Sechler, Ernest E., and Lois G. Dunn: AIRPLANE STRUCTURAL ANALYSIS AND DESIGN, Dover, 1963.

2.) G.C. MARSHALL SPACE FLIGHT CENTER ASTRONAUTIC STRUCTURES MANUAL.

3.) MIL-HDBK-5B

BY R. Page	GENERAL ELECTRIC	PAGE 82
CK.		MODEL TX
DATE REV.		REPORT Str. Anal.

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ALLOWABLE BOLT LOAD

BASIC AN PART NO.	THREAD T	RATED STRENGTH (POUNDS)					
		ULTIMATE TENSILE AT ROOT DIA		YIELD TENSILE AT ROOT DIA		SINGLE SHEAR AT FULL DIA	
		STEEL	AL ALLOY	STEEL	AL ALLOY	STEEL	AL ALLOY
AN3	NO. 10-32 NF-3A	2 210	1 100	1 690	710	2 125	990
AN4	1/4 -28 UNF-3A	4 080	2 030	3 130	1 310	3 680	1 715
AN5	5/16-24 UNF-3A	6 500	3 220	4 980	2 080	5 750	2 685
AN6	3/8 -24 UNF-3A	10 100	5 020	7 740	3 240	8 280	3 870
AN7	7/16-20 UNF-3A	13 600	6 750	10 430	4 350	11 250	5 250
AN8	1/2 -20 UNF-3A	18 500	9 180	14 190	5 920	14 700	6 850
AN9	9/16-18 UNF-3A	23 600	11 700	18 100	7 550	18 700	8 700
AN10	5/8 -18 UNF-3A	30 100	14 900	23 080	9 610	23 000	10 750
AN12	3/4 -16 UNF-3A	44 000	21 800	33 730	14 100	33 150	15 500
AN14	7/8 -14 UNF-3A	60 000	29 800	45 000	19 200	45 050	21 050
~~AN16~~	~~1 -14 NF-3A~~	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AN17	1 -12 UNF-3A	80 700	40 000	61 870	25 800	58 900	27 500
AN18	1-1/8 -12 UNF-3A	101 600	50 500	78 050	32 600	73 750	34 500
AN20	1-1/4 -12 UNF-3A	130 200	64 400	99 820	41 500	91 050	42 500

PROCUREMENT SPECIFICATION	AIR FORCE-NAVY AERONAUTICAL STANDARD	AN3 THRU AN20
MIL-B-6812	BOLT - MACHINE, AIRCRAFT	SHEET 4 OF

BY R. Page CK. DATE REV.	GENERAL ELECTRIC	PAGE B-3 MODEL STR REPORT Str. Anal.

STANDARD TEST RACK

MATERIAL 6061-T6 Aluminum

$F_{tu} = 42$ ksi $F_{su} = 27$ ksi

$F_{ty} = 35$ ksi

$F_{cy} = 35$ ksi $E = 10.5 \times 10^6$ psi

$F_{bru} = 67$ ksi

GRAPHS FOR PLATE ANALYSIS (Ref. 1)

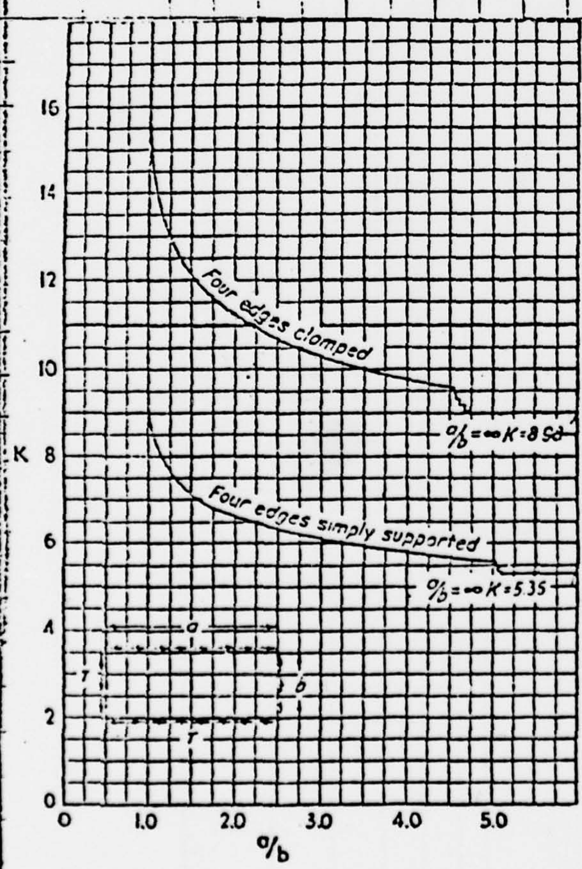


FIG. 5-11. Value of K for sheets under shear loads.

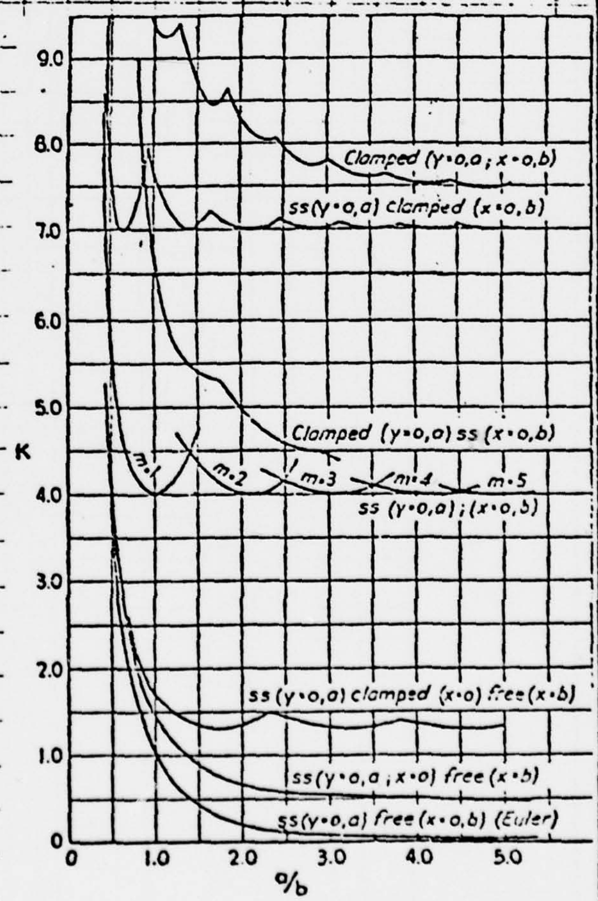


FIG. 5-8. Values of K versus a/b for various edge conditions.

GRAPH FOR BEAM CRIPPLING ANALYSIS (Ref. 2

Fig. 10

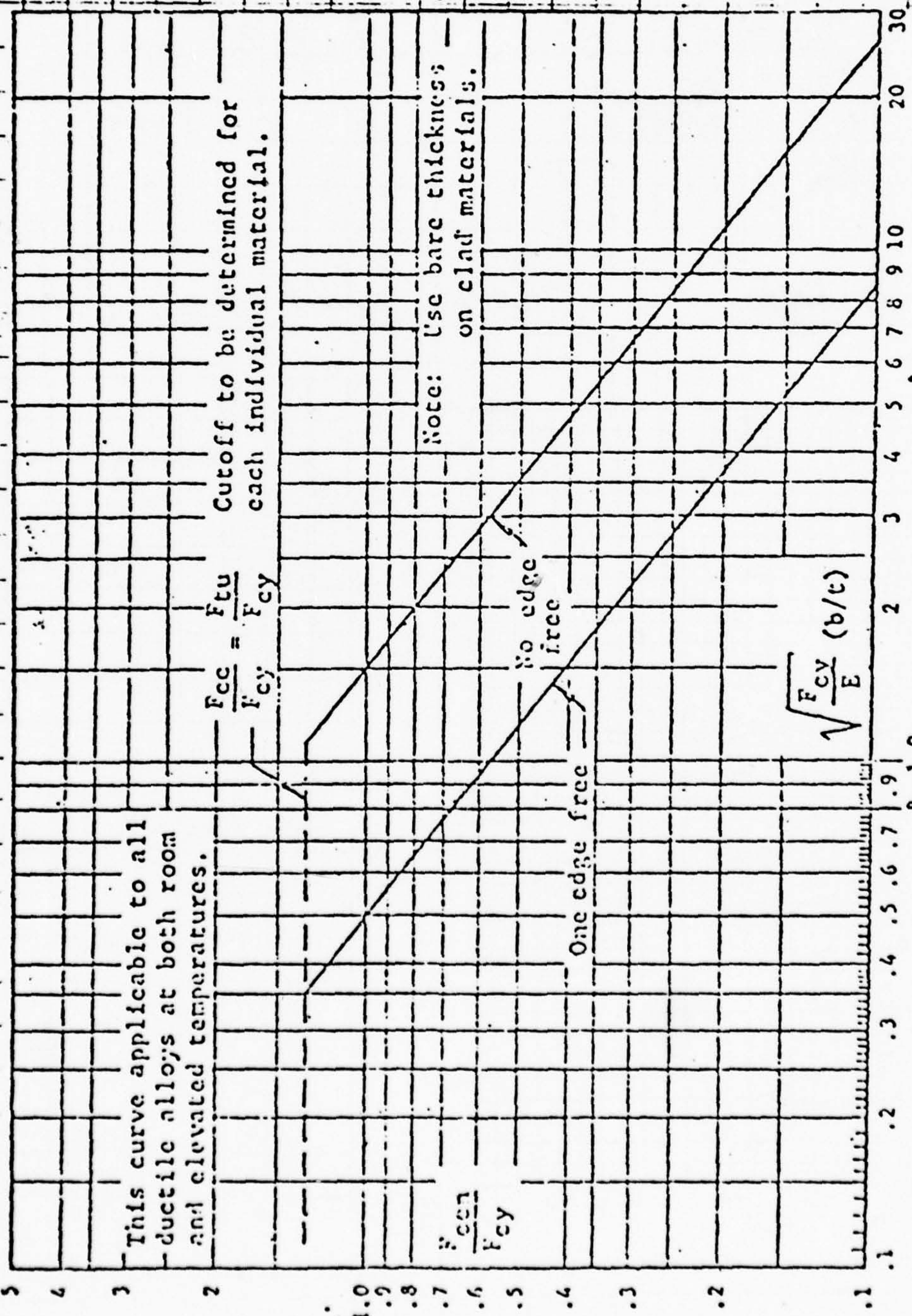
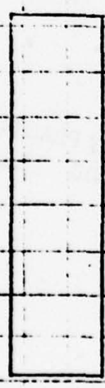


PLATE CALCULATIONS

THE CONSTRUCTION OF THE STR UTILIZES AS MUCH COMMONALITY AS POSSIBLE. THUS, THE EQUIPMENT MOUNTING PANELS USED ON THE BRIDGE AND ARCHED SECTION OF THE STR ARE THE SAME. SIMILARITY ALSO EXISTS BETWEEN THE SHEAR PANELS OF THE ARCH AND BRIDGE WHICH DO NOT HAVE COMPONENTS MOUNTED ON THEM.

SHEAR PANEL

$b = 5.$



$t = .1$

$a = 41.78$

$\frac{a}{b} = 8.356$ FROM FIGURES 5.8 & 5.11

$K_c = 4.$ $K_s = 5.35$

$\therefore F_{crc} = 14768$ psi

$F_{crs} = 19752$ psi

FROM THE NASTRAN RESULTS THE MOST HIGHLY STRESSED SHEAR PANELS ARE:

LOCATION	ELEMENT NO	LOAD CASE	σ_c PSI	τ PSI
BRIDGE	437	7	5751	3465
ARCH	427	7	4435	1912

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CK.		MODEL
DATE REV.		REPORT STR

MARGIN OF SAFETY

$$M.S. = \frac{1}{R_c + R_s^2} - 1$$

$$M.S._{BRIDGE} = \frac{1}{\frac{5750}{14768} + \left(\frac{3465}{19,752}\right)^2} - 1 = \underline{1.38}$$

$$M.S._{ARCH} = \frac{1}{\frac{4435}{14768} + \left(\frac{1912}{19,752}\right)^2} - 1 = \underline{2.23}$$

FORM 1-8139 B (9-59)

PLATE CALCULATIONS

EQUIPMENT CARRYING PANELS (MODELED AS ANISOTROPIC PLATES)

IN THE STR THE LOAD CARRING PANELS HAVE BEEN REINFORCED WITH AN010137 CHANNELS. IN THE NASTRAN MODEL THESE PLATES WERE MODELED AS HAVING ANISOTROPIC PROPERTIES. TO DETERMINE THE ACTUAL STRESSES IN THESE PLATES A SAP MODEL WAS CONSTRUCTED WHICH CLOSELY REPRESENTED THE CHANNEL STIFFENED PLATE. THE REACTIONS DETERMINED IN THE NASTRAN MODEL WERE APPLIED AS LOADS TO THIS SAP MODEL. THE RESULTS FROM THIS MODEL ARE USED IN THE FOLLOWING PLATE CALCULATIONS.

BY R. PAGE CK. DATE REV.	GENERAL ELECTRIC	PAGE 8-8 MODEL REPORT STR

SAP RESULTS -

THE LOADING OF THE SAP PLATE MODEL WAS OBTAINED FROM FOUR NODES OF THE NASTRAN MODEL. BECAUSE OF THIS, THE STRESSES OBTAINED IN THE THREE OUTER ROWS AND COLUMNS OF PLATES ARE NEGLECTED.

∴ CRITICAL PLATES

34, 35, 36, 37
44, 45, 46, 47
54, 55, 56, 57
64, 65, 66, 67

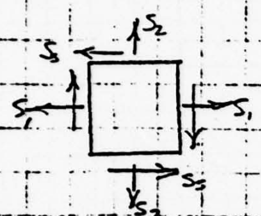
CRITICAL PLATES (LOOKING FOR MAXIMUM COMPRESSION + SHEAR)

PLATE	LOAD CASE	Sxx	Syy	Sxy	Mxx	Myy	Mxy
44	1	-271.6	-835	-468.7	.0071	.0168	.00642
54	1	-267.8	-821.3	-579.2	-.00248	-.0628	-.00503
67	1	2.4	98	-874	-.00534	-.0211	.00106

$\sigma_A = \frac{S}{t}$ $\sigma_B = \frac{6M}{t^2}$

PLATE CALCULATIONS

FROM ROARK: (NEGLECTING BENDING)



BIAXIAL STRESS COMBINED WITH SHEAR

$$\text{PRINCIPAL STRESSES} = \frac{1}{2}(S_1+S_2) \pm \sqrt{\left(\frac{S_1-S_2}{2}\right)^2 + S_s^2}$$

$$\text{MAX } S_p = \sqrt{\left(\frac{S_1-S_2}{2}\right)^2 + S_s^2}$$

FOR PLATE 44

$$S_p = \sqrt{\left(\frac{-271+835}{2(.1)}\right)^2 + \left(\frac{-468.7}{.1}\right)^2} = \underline{5470\ psi}\ \text{(SHEAR)}$$

$$\text{PRINCIPAL STRESS} \atop \text{(COMPRESSIVE)}\ \ \frac{1}{2}\left(\frac{-271-835}{.1}\right) - 5470 = \underline{-11,000\ psi}$$

FOR PLATE 54 $$S_p = \sqrt{\left(\frac{-267.8+821.3}{(.1)\cdot 2}\right)^2 + \left(\frac{579.2}{.1}\right)^2} = \underline{6419}\ \text{(SHEAR)}$$

$$\text{PRINCIPAL STRESS} \atop \text{(COMPRESSIVE)}\ \ \frac{1}{2}\left(\frac{-267.8-821.3}{.1}\right) - 6419 = \underline{-11,864\ psi}$$

FOR PLATE 67 $$S_p = \left\{\left(\frac{2.4-48}{2(.1)}\right)^2 + \left(\frac{874}{.1}\right)^2\right\}^{\frac{1}{2}} = 8742\ psi\ \text{(SHEAR)}$$

$$\text{PRINCIPAL STRESS} = \frac{1}{2}\left(\frac{2.4+48}{.1}\right) - 8742 = \underline{-8500\ psi}$$

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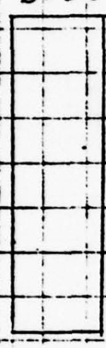
PLATE CALCULATIONS

EQUIPMENT PANELS

$b = 3.5''$



$t = .1''$ $\qquad \frac{a}{b} = 13.11$ $\qquad$ FROM FIGURES 5.8 & 5.11

$a = 45.88''$

$k_c = 4.0 \qquad k_s = 5.35$

$$F_{CR} = k \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

$F_{CR_c} = 30138$ psi

$F_{CR_s} = 40310$ [THIS IS GREATER THAN F_{su}. USE F_{su}]

$F_{CRS} = 27{,}000$ psi

USING PLATE 54 FOR THE MAJOR COMPRESSIVE STRESS AND PLATE 67 FOR THE MAXIMUM SHEAR

$$\text{MARGIN OF SAFETY} = \frac{1}{R_c + R_s^2} - 1 \quad \text{(CONSERVATIVE)}$$

$$\text{MARGIN OF SAFETY} = \frac{1}{\frac{11{,}864}{30138} + \left(\frac{8742}{27{,}000}\right)^2} - 1 = \underline{1.00}$$

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COMPONENT MOUNTING

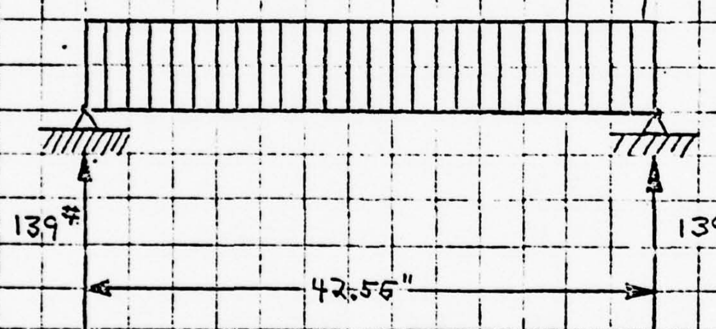
CONSIDERING THE MOST CRITICAL EQUIPMENT LOAD CARRYING PANNEL, THAT ON WHICH THE 444 LB. HEAT CAPACITOR IS MOUNTED, AND DISTRIBUTING THE LOAD FROM THE HEAT CAPACITOR UNIFORMLY OVER THE ENTIRE PLATE ~

LOAD FACTOR = 10

$$P_{CHANNEL} = \frac{444 \times 10}{16} = 277.5 \text{ LBS/CHANNEL}$$

$P = 277.5^{\#}$

$w = \frac{277.5}{42.55} = 6.5 \text{ \#/in}$



$$M_{MAX} = \frac{1}{8} \times 277.5 \times 42.55 = 1476 \text{ IN-LBS}$$

FOR AND10137-1012 CHANNEL (LOWEST INERTIA)

$C = .50$ IN $\qquad I = .0643$ IN^4

$$F_B = \frac{1476 \times .50}{.0643} = 11.5 \text{ KSI}$$

$F_{TU} = 42$ KSI

$$MS = \frac{42}{11.5} - 1 = \underline{\underline{+2.66}}$$

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COMPONENT MOUNTING

CHECKING FLANGE OF 9" HIGH CHANNEL CARRING REACTION LOADS FROM AND10137 CHANNEL ~

FOR BENDING AS A TENSION CLIP (ASSUMED TO BE A DOUBLY FIXED BEAM) ~

$$M = 139 \times \frac{1.9}{2} = 132 \text{ IN-LBS.}$$

$t = .10$ IN $\qquad W_{EFF} = 2.6$ IN

$$f_B = \frac{6 \times 132}{2.6 \times .10^2} = 30.4 \text{ KSI}$$

$F_B = 62.2$ KSI FOR RECT. SEC - 6061-T6

$$MS = \frac{62.2}{30.4} - 1 = \underline{\underline{1.05}}$$

THE END OF THE AND10137-2008 OR -2406 CHANNEL WILL BE LESS CRITICAL THAN THE ABOVE.

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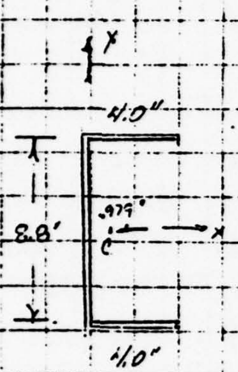
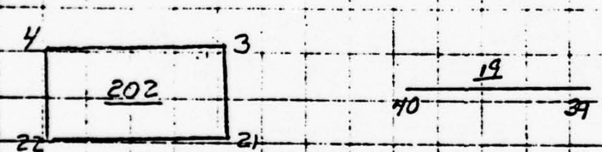
Critical 9" Deep Channel (Arch Member)



Thickness = 0.1"
Area = 1.68 in²
I_x = 21.52 in⁴
I_y = 2.661 in⁴

Critical Load Case 8   Beam composed of Elements 19 & 202



Element No.	Grid	T1	T2	T3	R1	R2	R3
202	3	-8.479 E-2	-8.177 E+2	-6.776E+3	0.0	1.213	-1.041
202	21	7.726 E-2	-2.753 E 3	5.475 E 3	0.0	-1.152	1.102
19	39	-1.225 E1	7.149 E 2	5.972 E 2	3.405 E 3	6.084 E 2	-5.483 E 2
202	4	6.142 E-2	-5.000 E3	+3.260 E 3	0.0	1.224	-1.019
202	22	-5.389 E-2	3.064 E 3	4.562 E3	0.0	-1.1475	1.1079
19	40	1.225 E1	-7.149 E2	-5.972 E2	2.646 E3	-1.904 E 2	1.720 E 2

Note: These are forces on the grid by element

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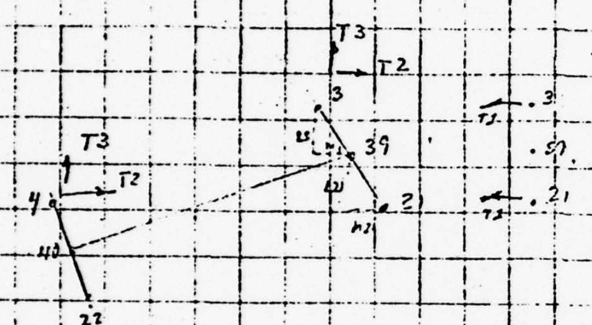
9" DEEP CHANNEL CON'T'D

CONVERT ALL FORCES TO CENTROID OF BEAM PTS 39, 40



DETERMINATION OF:

$L3 = 36.5079 - 34.5354 = 1.9725$
$M3 = -70.8209 + 74.8659 = 4.0450$
$L21 = 38.48 - 36.5079 = 1.9721$
$M21 = -74.8659 + 78.91 = 4.0441$
$L4 = 70.6344 - 66.8181 = 3.8163$
$M4 = -41.7602 + 44.1453 = 2.3851$
$L22 = 74.45 - 70.6344 = 3.8156$
$M22 = -44.1453 + 46.53 = 2.3847$

END 39

AT GRID 3 $\quad -T2_3 \times L3 - T3_3 \times M3 = R1_3$

21 $\quad T2_{21} \times L21 + T3 \times M21 = R1_{21}$

$$R1_T = R1_{39} + R1_3 + R1_{21}$$

$R1_3 = +8177E2 \times 1.9725 + 6.776E3 \times 4.0450 = 2.902E4$
$R1_{21} = 2.753E3 \times 1.9721 + 5.475E3 \times 4.0441 = 2.757E4$
$R1_T = 3.405E3 + 2.902E4 + 2.757E4 = \underline{6.000E4}$ in-lb

3 $\quad T1_3 \times L3 = R2_3 = -8.48E-2(1.9725) = \sim 0.$

21 $\quad -T1_{21} \times L21 = R2_{21} = 7.726E-2(1.9721) = \sim 0.$

$$R2_T = R2_{39} + R2_3 + R2_{21} = \underline{6.084E2} \text{ in-lb}$$

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9" DEEP CHANNEL CON'T'D

END 39

$3 \quad T1_3 \times M3 = R3_3 = \sim 0.$

$21 \quad T1_{21} \times M21 = R3_{21} = \sim 0.$

$R3_T = R3_{39} + R3_3 + R3_{21} = \underline{5.972\,E2}^{\text{in-\#}}$

$T1_T = T1_{39} + T1_3 + T1_{21} = \underline{-12.26^{\#}}$

$T2_T = T2_{39} + T2_3 + T2_{21} = -8.17E2 + 2.753E3 + 7.1?E2$
$= \underline{2650^{\#}}$

$T3_T = T3_{39} + T3_3 + T3_{21} = \underline{704.80^{\#}}$

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9" DEEP CHANNEL

USING THE SAME THEORY FOR END 40

$T1_T = T1_{40} + T1_4 + T1_{22} = \underline{12.25^{\#}}$

$T2_T = T2_{40} + T2_4 + T2_{22} = -7.149E2 + -5.00E3 + 3.064E3 = \underline{-2650^{\#}}$

$T3_T = T3_{40} + T3_4 + T3_{22} = -5.972E2 + -326E3 + 4.562E3 = \underline{704.80^{\#}}$

$-T2_4 \times L4 - T3_4 \times M4 = R1_4 = +5E3 \times 3.8163 + 3.26E3 \times 2.3851 = 26860$

$-T2_{22} \times L22 + T3_{22} \times M22 = R1_{22} = 3.064E3 \times 3.8156 + 4.562E3 \times 2.3847 = 22570$

$R1_T = R1_{40} + R1_4 + R1_{22} = 2.646E3 + 49427 = 5.207E4$

$T1_4 \times L4 = R2_4 = \sim 0.$

$-T1_{22} \times L22 = R2_{22} = \sim 0.$

$R2_T = R2_{40} + R2_4 + R2_{22} = -1.904E2$

$T1_4 \times M4 = R3_4 \sim 0.$

$-T1_{22} \times M22 = R3_{22} \sim 0.$

$R3_T = R3_{40} + R3_4 + R3_{22} = 172$ in-#

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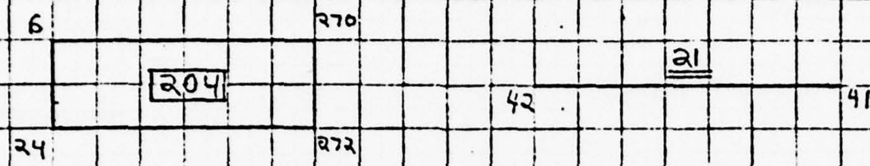
9" DEEP CHANNEL

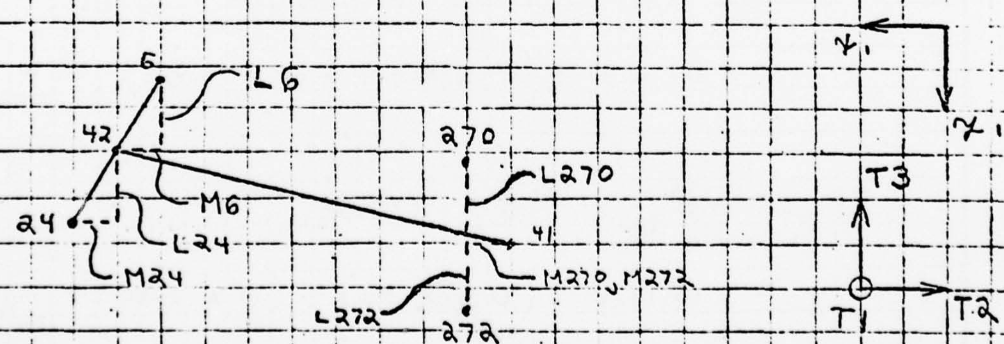
LOAD CASE #8 - BEAM COMPOSED OF ELEMENTS 21 & 204



ELEM	GRID	T1	T2	T3	R1	R2	R3
204	6	0	3365.7	-3717.6	0	0	0
204	24	0	-3743.7	1916.4	0	0	0
21	42	74.4	-981.2	68.3	-3998.9	-376.3	-1311.6
204	270	0	4093.4	-450.5	0	0	0
204	272	0	-3715.3	2251.6	0	0	0
21	41	-74.4	981.2	-68.3	-5414.0	-565.8	-1973.9

NOTE: THESE ARE FORCES ON THE GRID BY ELEMENT (FROM NASTRAN GRID POINT FORCE BALANCE)

CONVERTING ALL FORCES TO CENTROID OF BEAM (I.E. POINTS 42 AND 41)



L6 = 70.63 - 66.82 = 3.81 IN

M6 = 44.14 - 41.76 = 2.38 IN

L24 = 74.45 - 70.63 = 3.82 IN

M24 = 46.53 - 44.14 = 2.39 IN

L270 = 83.30 - 77.51 = 5.79 IN

M270 = 4.5 - 0 = 4.5 IN

L272 = 86.51 - 83.30 = 3.21 IN

M272 = 4.5 - 0 = 4.5 IN

9" DEEP CHANNEL
FOR END 42

$T1_{TOT} = 0 + 0 + 74.4 = \underline{\underline{74.4 \text{ LB.}}}$

$T2_{TOT} = 3365.7 - 3743.7 - 981.2 = \underline{\underline{-1359.2 \text{ LB.}}}$

$T3_{TOT} = -3717.6 + 1916.4 + 68.3 = \underline{\underline{-1732.9 \text{ LB.}}}$

$R1_{TOT} = R1_6 + R1_{24} + R1_{42}$

$R1_6 = -(3365.7 \times 3.81) - (3717.6 \times 2.38) = -21,671.2$

$R1_{24} = -(3743.7 \times 3.82) - (1916.4 \times 2.39) = -18,881.1$

$R1_{TOT} = -21,671.2 - 18,881.1 - 3,998.9 = \underline{\underline{-44,551.2 \text{ IN-LB}}}$

$R2_{TOT} = R2_{42} + R2_6 + R2_{24}$

$= -376.8 + (0 \times 3.81) + (0 \times 3.82) = \underline{\underline{-376.8 \text{ IN-LB}}}$

$R3_{TOT} = R3_{42} + R3_6 + R3_{24}$

$= -1311.6 + (0 \times 2.38) + (0 \times 2.39) = \underline{\underline{-1311.6 \text{ IN-LB}}}$

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9" DEEP CHANNEL

FOR END 41 (NOTE: THIS END IS AT KEEL TRUNNION)

$T1_{TOT} = 0 + 0 - 74.4 = \underline{-74.4 \text{ LB.}}$

$T2_{TOT} = 4093.4 - 3715.3 + 981.2 = \underline{1359.3 \text{ LB.}}$

$T3_{TOT} = -450.5 + 2251.6 - 68.3 = \underline{1732.8 \text{ LB.}}$

$R1_{TOT} = R1_{270} + R1_{272} + R1_{41}$

$R1_{270} = -(4093.4 \times 5.79) + (450.5 \times 4.5) = -21{,}673.5$

$R1_{272} = -(3715.3 \times 3.21) - (2251.6 \times 4.5) = -22{,}058.3$

$R1_{TOT} = -21{,}673.5 - 22{,}058.3 - 5414.0 = \underline{-49{,}145.8 \text{ IN-LBS}}$

$R2_{TOT} = R2_{41} + R2_{270} + R2_{272}$

$= -565.8 - (0 \times 5.79) + (0 \times 3.21) = \underline{-565.8 \text{ IN-LBS}}$

$R3_{TOT} = R3_{41} + R3_{270} + R3_{272}$

$= -1973.9 + (0 \times 4.5) + (0 \times 4.5) = \underline{-1973.9 \text{ IN-LBS}}$

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9" DEEP CHANNEL

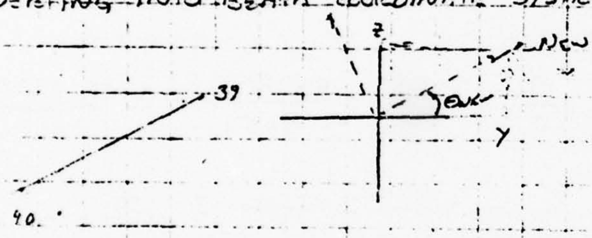
GRID	T1	T2	T3	R1	R2	R3
39	-12 #	2650 #	-705 #	60,000 "#	608 "#	597 "#
40	12 #	-2650 #	705 #	52,000 "#	-190 "#	172 "#
41	-74 #	1359 #	1733 #	-49,146 "#	-566 "#	-1974 "#
42	74 #	-1359 #	-1733 #	-44,551 "#	-377 "#	-1312 "#

5" Deep Channel Con'td

GRID	T1	T2	T3	R1	R2	R3
39	-12.26#	2650#	705#	6.00E4 in-#	6.08E2 in-#	5.972E2 in-#
40	12.25#	-2650#	705#	5.20E4 in-#	-1.904E2 in-#	1.72E2 in-#

Node 40 not critical stresses

Converting into beam coordinate system



GRID 39

T2 = 2650 R = 2742.18 ∠ 14.8578

T3 = 705

R2 = 6.08E2 R = 852.10 ∠ 44.4770

R3 = 5.972E2

$$\Theta_{NEW} = \tan^{-1} \frac{70.6344 - 36.5079}{-44.4453 + 74.8659} = 48.0065°$$

$$\Theta_{DIFF} = \Theta_{NEW} - \Theta_R = 48.0065 - \Theta_R$$

$$F_{AXIAL} = R \cdot \cos \Theta_{DIFF}$$

$$F_{SHEAR} = -R \cdot \sin \Theta_{DIFF}$$

For Grid 39 $F_{AXIAL} = 2742.18 \cos(48.0065 - 14.8578) = 2297^{\#}$ (Compression)

$F_{SHEAR} = -2742.18 \sin(48.0065 - 14.8578) = -1498^{\#}$ (Shear)

$\text{Moment}_Y = -852.10 \sin(48.0065 - 44.4770) = -52.46 \text{ in-\#}$

$\text{Moment}_{Torque} = +852.10 \cos(48.0065 - 44.4770) = 850.5 \text{ in-\#}$

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9" Deep Channel Con'td

Maximum Element Stress at Node 39

$M_x = 6.00E4$ in-#.

$M_y = -52.46$ in-#

$P = -2297$ #

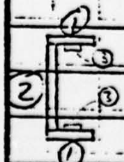
$$\sigma = \frac{P}{A} \pm \frac{Mc}{I_x} \pm \frac{Mc}{I_y} = \frac{-2297}{1.68} \pm \frac{6.00E4(4.5)}{21.52} \pm \frac{52.5(3.02)}{2.661}$$

$$= -1367 \pm 12546 \pm 59$$

$$= 13972 \text{ psi Compression}$$

Crippling Analysis presented in PIR 1R53-555

CHECK FOR CRIPPLING (Fig. 10) Page 4



	b	t	$\frac{b}{t}\sqrt{\frac{F_{cy}}{E}}$	F_{ccn}/F_{cy}	F_{ccn}	bt	P_{ccn}
①	4.0	0.1	2.44	.275	10.73 ksi	.40	4.29 K
②	8.8	0.1	5.36	.35	13.65 ksi	.88	12.01 K
③	2.0	0.1	1.22	.275	10.73 ksi	.20	2.15 K

9" DEEP CHANNEL ...

ASSUME PURE BENDING DUE TO SMALL AXIAL FORCE

USING REF 2: G.C. MARSHALL SPACE FLIGHT CENTER ASTRONAUTIC STRUCTURES MANUAL

$$M_{cr} = 2\left(\underbrace{\Sigma F_{ccn} b_n t_n \bar{y}_n}_{\text{For flange members}} + \underbrace{\Sigma F_{ccm} b_m t_m \bar{y}_m / 2}_{\text{For web members}}\right)$$

$$M_{cr} = 2\left[4.29^{K} \times 4.45'' + 12.01^{K} \times \tfrac{2}{3}(4.4'') + 2.15^{K} \times 4.45\right]$$

$$= 127^{\,''K}$$

$$MS = \frac{127^{\,''-K}}{60^{\,''-K}} - 1 = \underline{\underline{1.12}}$$

MARGIN OF SAFETY AGAINST CRIPPLING FAILURE

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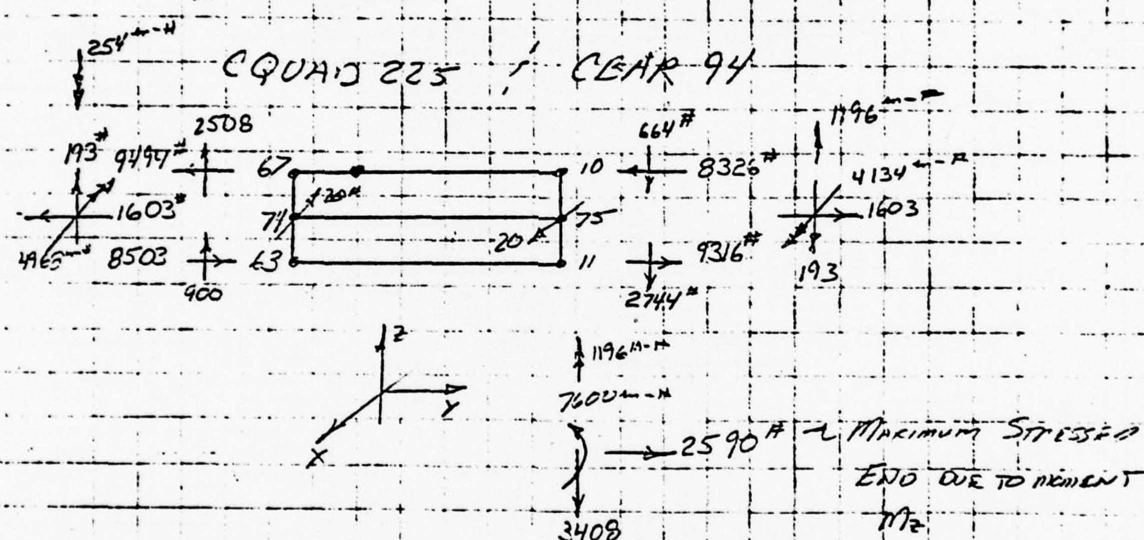
9" DEEP CHANNEL — CRITICAL BRIDGE MEMBER

CRITICAL LOAD CASE 8

HIGHLY STRESSED CHANNEL COMPOSED OF –

CQUAD 225 ; CBAR 94



$$\sigma = \frac{P}{A} \pm \frac{M_x C}{I_x} \pm \frac{M_y C}{I_y} = \frac{2590}{1.68} \pm \frac{7600^{in\text{-}lb}(4.5)}{2.52} \pm \frac{1196(3.02)}{2.661}$$

$$\sigma = 1541 \pm 7588 \pm 1357$$

= 4486 psi TENSION
−1404 psi COMPRESSION

SINCE TENSION IS 4X COMPRESSION STRESS
∴ TENSION LOAD CRITICAL

$$MS = \frac{35}{\left(\frac{14.4}{1.4}\right)} - 1 = \underline{\underline{10}} \quad \text{(YIELD)}$$

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9" CHANNEL - BRIDGE MEMBER

CHECK FOR SHEAR FAILURE

$$\sigma_s = \frac{3}{2}\frac{P}{A} = \frac{3}{2}\frac{[illegible]}{9(.1)} = 5680 \text{ psi (ULT)}$$

$$MS = \frac{43}{5.68} - 1 = \boxed{6.6} \quad \text{(SHEAR ULT)}$$

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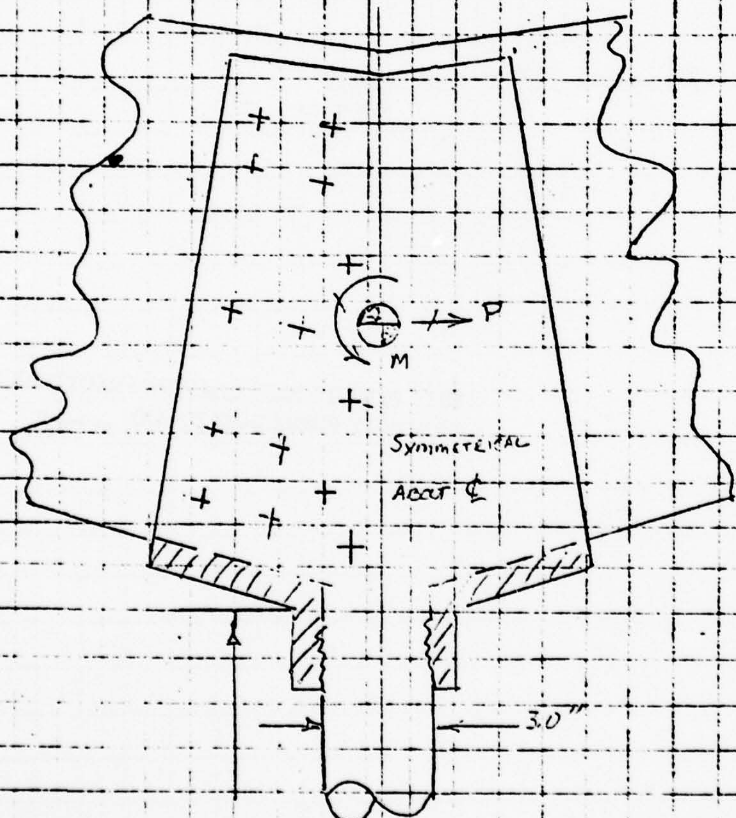
KEEL TRUNNION

THE MAXIMUM LOAD FOR THE KEEL TRUNNION OCCUR IN SUBCASES 4 AND 5 OF THE NASTRAN LOADS ANALYSIS

R_y MAX = 10,500#



ALL BOLTS SHOWN ARE 5/16" DIA

9.6'

10,500# GRID POINT 57

THE 10,500# LOAD IS FIRST TRANSFERRED TO THE THREADED PART OF THE FITTING. THE LOAD IS THEN TRANSFERRED THROUGH THE BOLT PATTERN INTO THE FRAMED CHANNEL.

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KEEL TRUNNION

THREAD CHECK

THE BENDING MOMENT APPLIED TO THE THREADED AREA IS:

$$10500(9.6) = 100800 \text{ in-\#} \quad (\text{ULT})$$

THE EQUIVALENT AXIAL LOAD IS:

$$P_A = \frac{2M}{R} = \frac{2(100800)}{1.5} = 134,400^{\#}$$

THREAD ALLOWABLE STRENGTH IS GIVEN BY

$$P_E = A_E\, L\, S$$

WHERE P_E = STRENGTH OF EXTERNAL THREAD
L = ENGAGEMENT LENGTH
S = MATERIAL SHEAR STRENGTH
A_E = EXTERNAL THREAD AREA

$A_E = 5.23 \text{ in}^2$ (FOR 3-12UN-2A THREAD)
$L = 1.25$
$S = 46000$ (7075-T6 MIL HDBK 5-B BAR REF 3)

$$\therefore P_E = 5.23(1.25)(46000) = 300,725^{\#}$$

$$MS = \frac{300,725}{134,400} - 1 = \underline{\underline{1.24}}$$

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KEEL TRUNNION

BOLT ATTACHMENT CHECK

LOCATION OF CG OF BOLT PATTERN

A	d	Ad
1	1.5	1.5
1	2.15	2.15
1	2.5	2.5
1	2.65	2.65
1	3.40	3.40
2	3.90	7.80
1	5.60	5.60
1	6.05	6.05
1	6.20	6.20
1	7.8	7.8
1	8.28	8.28
1	9.05	9.05
1	9.50	9.50
14		72.48

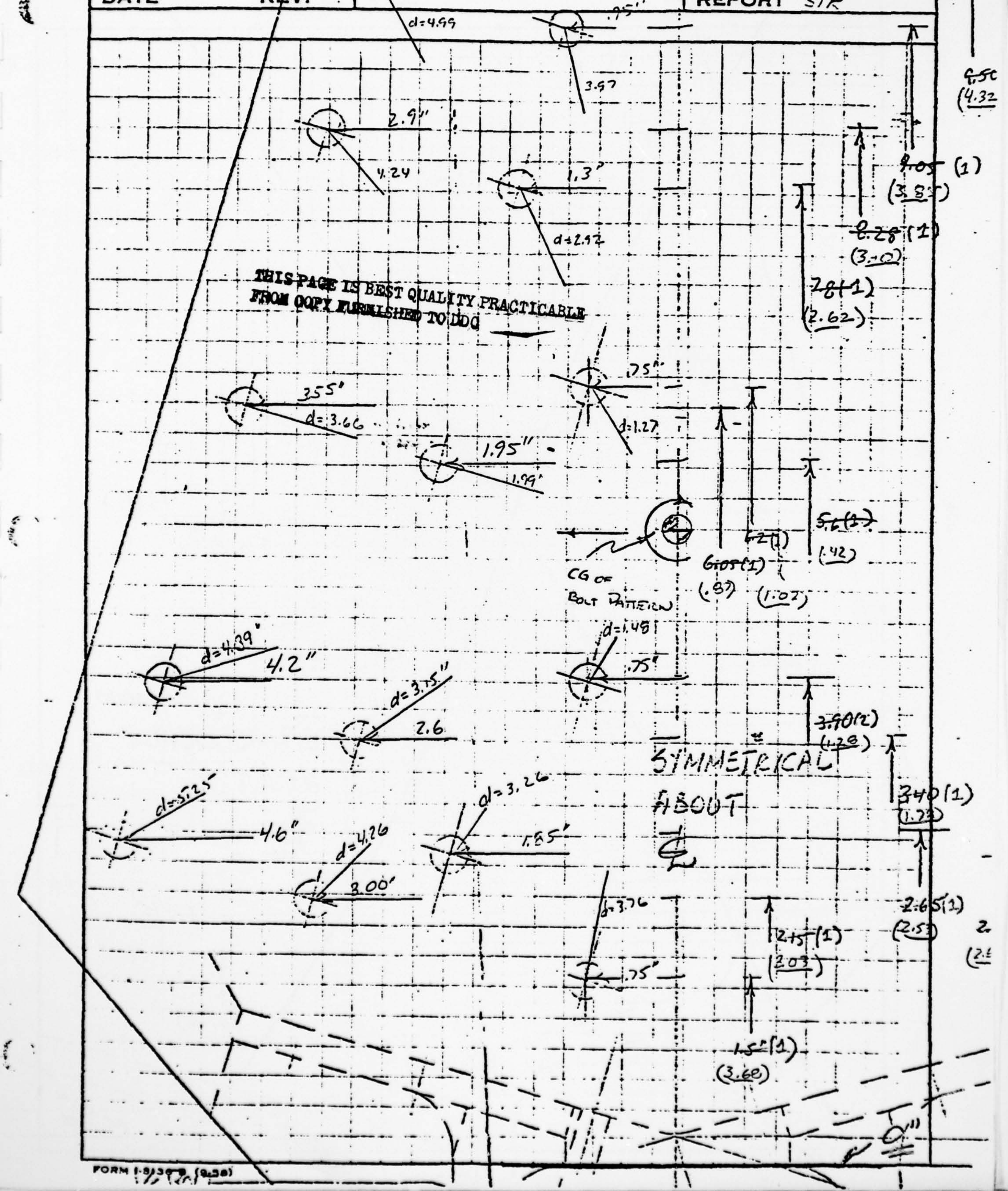
$\bar{d} = \frac{Ad}{A} = \frac{72.48}{14} = 5.18"$ FROM O MARK

LOADS @ BOLT PATTERN CG

$P = 10,500^{\#}$

$M = 10,500^{\#}(5.18 + 9.6) = 155,190^{\#\text{-in}}$

BY R. Page CK. DATE REV.	GENERAL ELECTRIC	PAGE B-29 MODEL REPORT STR



AD-A066 247 GENERAL ELECTRIC CO PHILADELPHIA PA SPACE DIV F/G 14/2

STANDARD TEST RACK. CONCEPT DEFINITION STUDY. STRUCTURAL ANALYS--ETC(U)

JAN 79 F04701-77-C-0116

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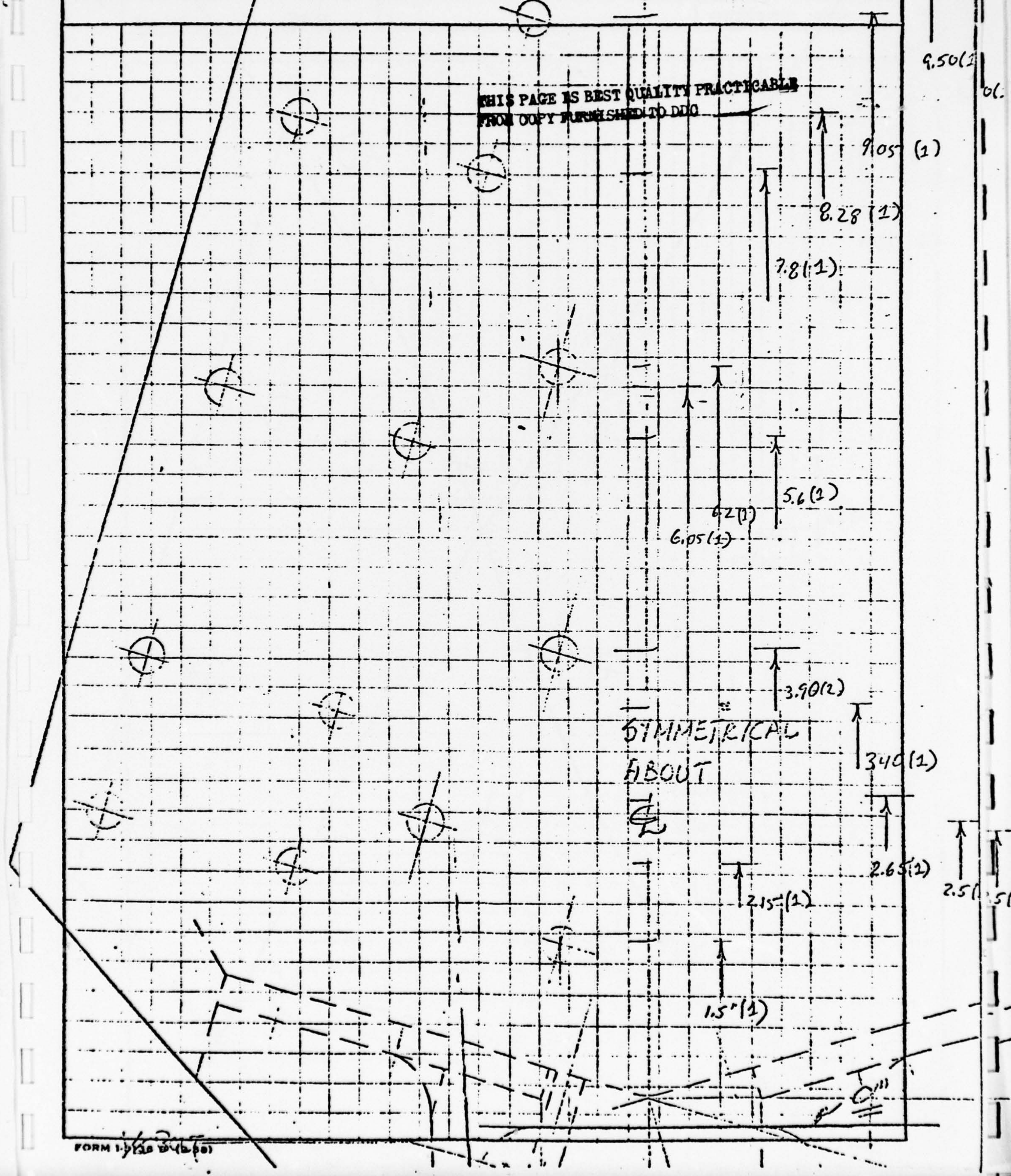

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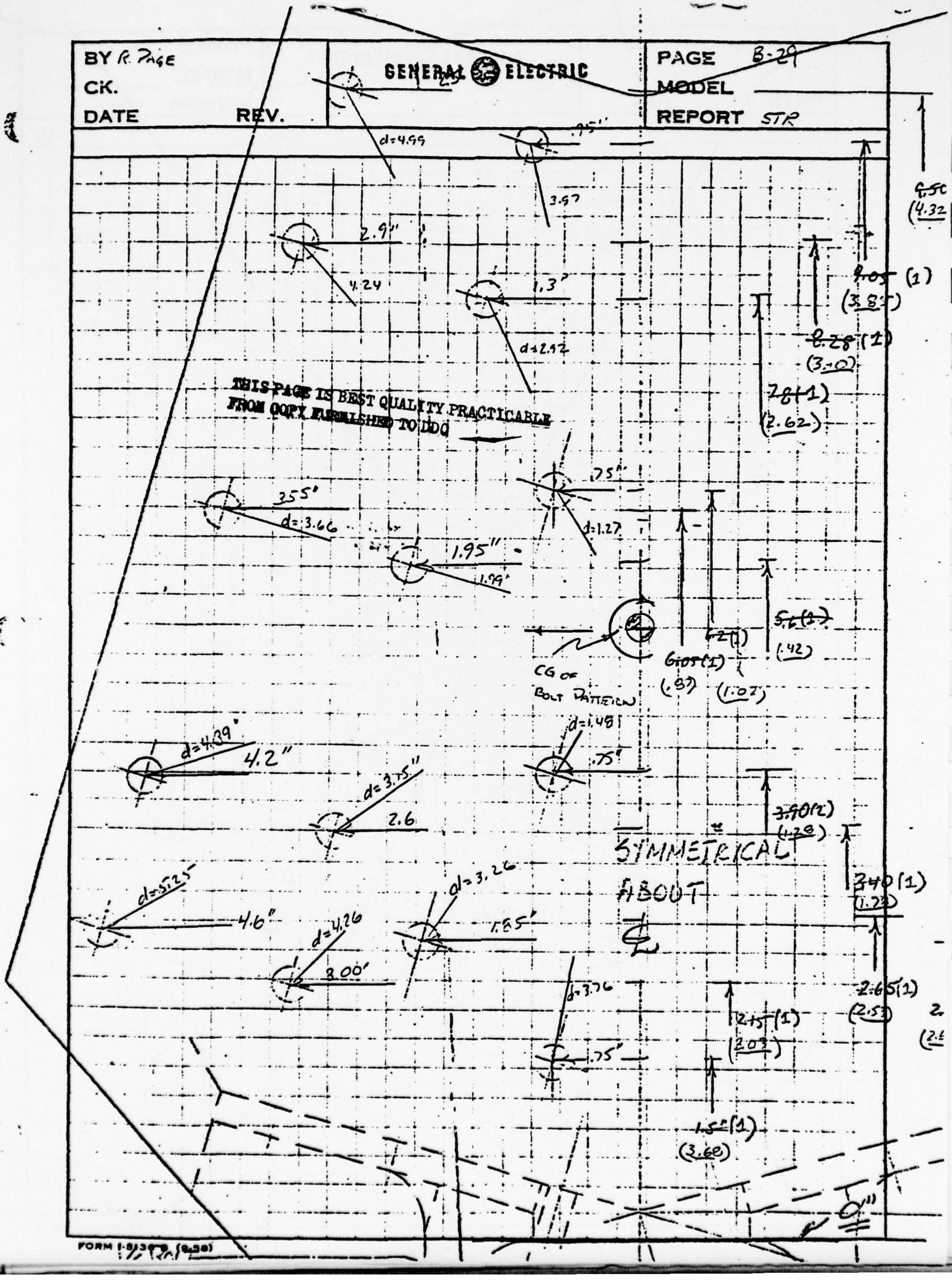

FORM 1-81368 (8-58)

BY R. PAGE	GENERAL ELECTRIC	PAGE 831
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KEEL TRUNNION

MAXIMUM BOLT LOAD OCCURS IN THE LOWER CORNER ATTACHMENT

$$P_{SH} = \frac{10,500^{\#}}{14} = 750^{\#}$$

$$P_m = \frac{Md}{\Sigma d^2} = \frac{155,190^{\#} \div (5.25)}{376}$$

$\Sigma d^2 = 2(3.76^2 + 3.26^2 + 4.26^2 + 5.25^2 + 3.15^2 + 4.31^2$
$+ 1.49^2 + 1.77^2 + 3.66^2 + 1.27^2 + 2.32^2 + 3.27^2$
$+ 4.99^2 + 3.97^2) = 376\ in^2$

$P_m = 2167^{\#}$

$P_T = (2167^2 + 750^2)^{1/2} = 2293^{\#}$

BEARING STRESS IN FITTING

$$f_{br} = \frac{2293}{.25(.3125)} = 29,400\ LBS/in^2\ (ULT)$$

$F_{bru} = 123\ ksi$ FOR 7075 T6 MIL HDBK-5B

$$MS = \frac{123}{29.4} - 1 = \underline{\underline{3.19}}$$

BEARING STRESS IN FORMED CHANNEL AND DOUBLER PLATE

THE .1 THICK 6061 CHANNEL AND THE 0.2 IN THICK 7075 DOUBLER WILL DEVELOP A BEARING STRENGTH EQUIVALENT TO THE .25 7075 MATERIAL PREVIOUSLY CALCULATED

$\therefore$ MS = 3.19

FORM 1-8136 B (3-58)

KEEL TRUNNION FITTING

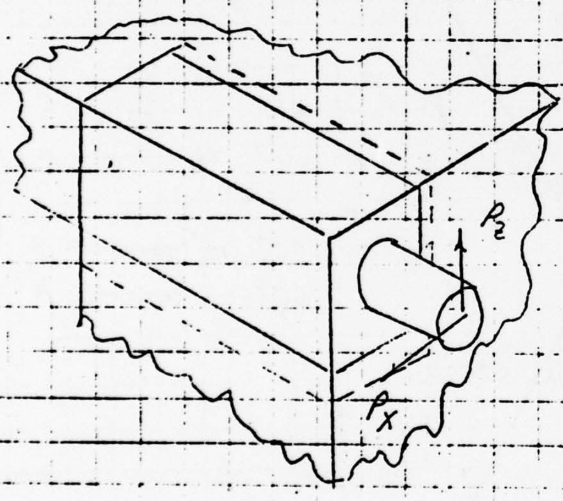
SHEAR FAILURE

ASSUMING 5/16 BOLT USED ULTIMATE SHEAR STRENGTH=5750#

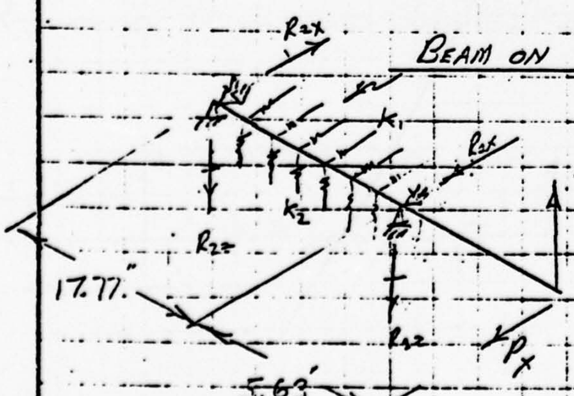
$$MS = \frac{5750}{2293} - 1 = 1.50$$

TRUNNION FITTING

THE TRUNNION FITTING LOADS ARE TRANSFERRED TO THE STR MAIN STRUCTURE AS SHOWN BELOW



BEAM ON ELASTIC FOUNDATION



NOTE: CALCULATIONS INDICATE THE ELASTIC FOUNDATION HAS LITTLE EFFECT ON THE REACTIONS OF THE BEAM. THEREFORE

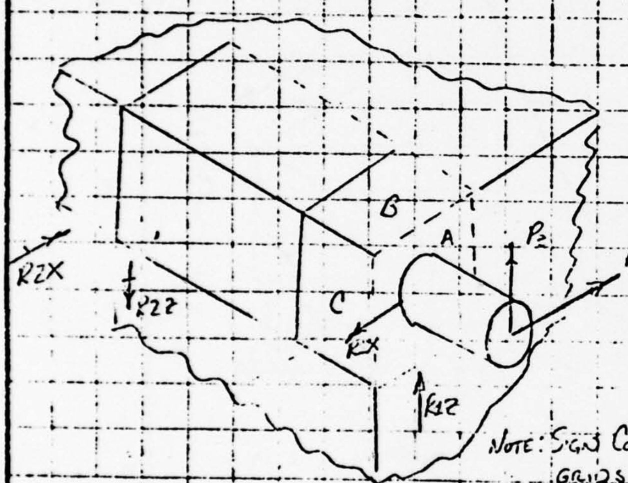
K_1 & $K_2 = 0$

BY R. Page CK. DATE REV.	GENERAL ELECTRIC	PAGE B-34 MODEL REPORT STR

TRUNNION FITTING

THE TRUNNION FITTING LOADS P_x & P_z ARE REACTED INTO THE STR STRUCTURE BY FITTINGS AT AREAS A, B, & C.

DISTRIBUTION OF LOADS IS INTENTIONALLY ASSUMED CONSERVATIVE AS FOLLOWS:



NOTE: SIGN CONV. FOR GRIDS 57-58

P_{1x} LOAD 60% TO SURFACE A
60% TO SURFACE B

P_{1z} LOAD 60% TO SURFACE C
60% TO SURFACE A

OVERLAPPING ASSUMPTION (CONSERVATIVE)

FOR SURFACE A THE CRITICAL LOADING CONDITION IS SUBCASE 6, GRID 57

FOR SURFACE B THE CRITICAL LOADING CONDITION IS SUBCASE 6, GRID 57

FOR SURFACE C THE CRITICAL LOADING CONDITION IS SUBCASE 7, GRID 58

∴ FOR THE CRITICAL LOADS OF SUBCASE 6

$P_x = 14490^{\#}$ $\quad P_z = 2506^{\#}$

FORM 1-6136 B (9-58)

TRUNNION FITTING

THE MAXIMUM LOADS (ULTIMATE) AT THE FOUR SHUTTLE INTERFACE GRID POINTS FOR THE DESIGN LOADING CONDITIONS ARE OBTAINED FROM THE NASTRAN FINITE-ELEMENT ANALYSIS

CONDITION	GRIDPOINT	LOADS (POUNDS) T_1	T_2	T_3
SUBCASE 6	55	12,380#	0.0	29.4
SUBCASE 8	56	0.0	0.0	14050#
SUBCASE 6	57	14490	0.0	2506#
SUBCASE 7	58	0.0#	0.0#	-14140#

THE CRITICAL LOADS OCCUR IN SUBCASES 6 & 7, TRUNNION FITTINGS OF GRID POINTS 57 & 58

TRUNNION FITTING CON'T'D

THE REACTIONS FROM THESE LOADS ARE:

$$R_{1Z} = \frac{5.63+17.77}{17.77}(2506) = 3300^{\#}$$

$$R_{2Z} = \frac{5.63}{17.77}(2506) = 794^{\#}$$

$$R_{1X} = \frac{5.63+17.77}{17.77}(14490) = 19{,}080^{\#}$$

$$R_{2X} = \frac{5.63}{17.77}(14490) = 4590^{\#}$$

THE TOTAL LOADS AT SURFACES A & B FOR THE R_Z AND R_X LOADS ARE SHOWN ABOVE AND ARE THEREFORE:

$$\underline{\text{SURFACE A}} = .60(3300) + .60(19{,}080) = \underline{13{,}430^{\#}}$$

$$\underline{\text{SURFACE B}} = .60(19{,}050) = \underline{11{,}450^{\#}}$$

FOR SURFACE C THE CRITICAL LOADING CONDITION IS SUBCASE 7

TRUNNION FITTING CON'TD

THE REACTIONS FROM THE SUBCASE 7 LOAD

$$P_z = -14{,}140^{\#}$$

THE R_{1z} REACTION FROM THESE LOADS

$$R_{1z} = \frac{5.63 + 17.77}{17.77}(-14{,}140) = 18620^{\#}$$

THE MAXIMUM TOTAL LOAD TO SURFACE C IS:

$$\text{SURFACE } C = .60(18620^{\#}) = 11{,}170^{\#}$$

THE ABOVE LOADS ARE USED TO CHECK THE TRANSFER OF TRUNNION LOADS TO THE SUPPORT FITTING. LOAD DISTRIBUTIONS ARE SHOWN IN THE FOLLOWING SKETCHS

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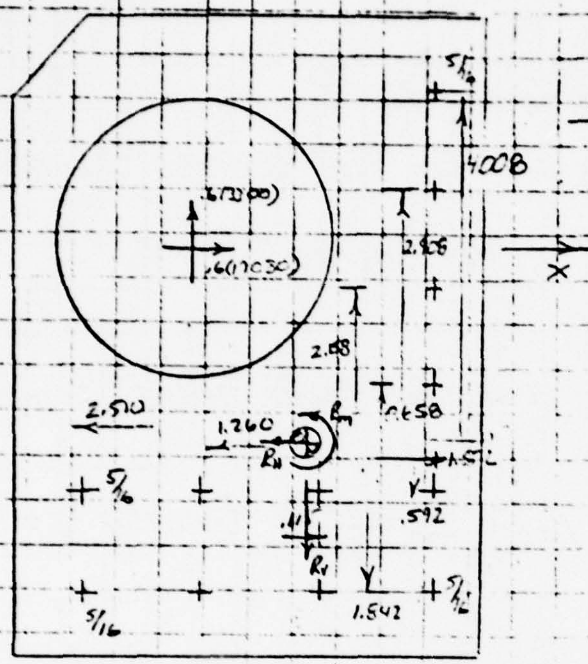

CALCULATION OF CG LOCATION

(SEE PAGE 34 FOR DIMENSIONS)

A	d_z	Ad_z
4	6.75	27.0
4	5.5	22.0
1	4.25	4.25
1	2.75	2.75
1	2.0	2.0
1	.9	.9
12		58.9

FOR Z LOCATION

$$\bar{d_z} = \frac{58.9}{12} = 4.908 \text{ in}$$

(FROM TOP EDGE)

A	d_x	Ad_x
6	5 1/8	30.75
2	3.688	7.375
2	2.313	4.625
2	1.063	0.125
12		42.375

FOR X CG LOCATION

$$\bar{d_x} = \frac{A d_x}{A} = \frac{42.875}{12} = 3.573 \text{ in} \quad \text{(FROM SIDE EDGE)}$$

$$\Sigma d^2 = 74.84 \quad \text{(SEE BELOW)}$$

d_{max} FROM CENTROID $= 4.298$ inches FROM CENTROID TO UPPER RIGHT CORNER

$$\Sigma d^2 = \Sigma H^2 + \Sigma V^2$$

$$= 6(1.552)^2 + 2(1.5)^2 + 2(1.260)^2 + (2.510)^2 + 4(1.842)^2 + 4(.592)^2$$
$$+ (.658)^2 + (2.56)^2 + ([illegible])^2 + (4.008)^2$$

FORM 1-8136 B (9-38)

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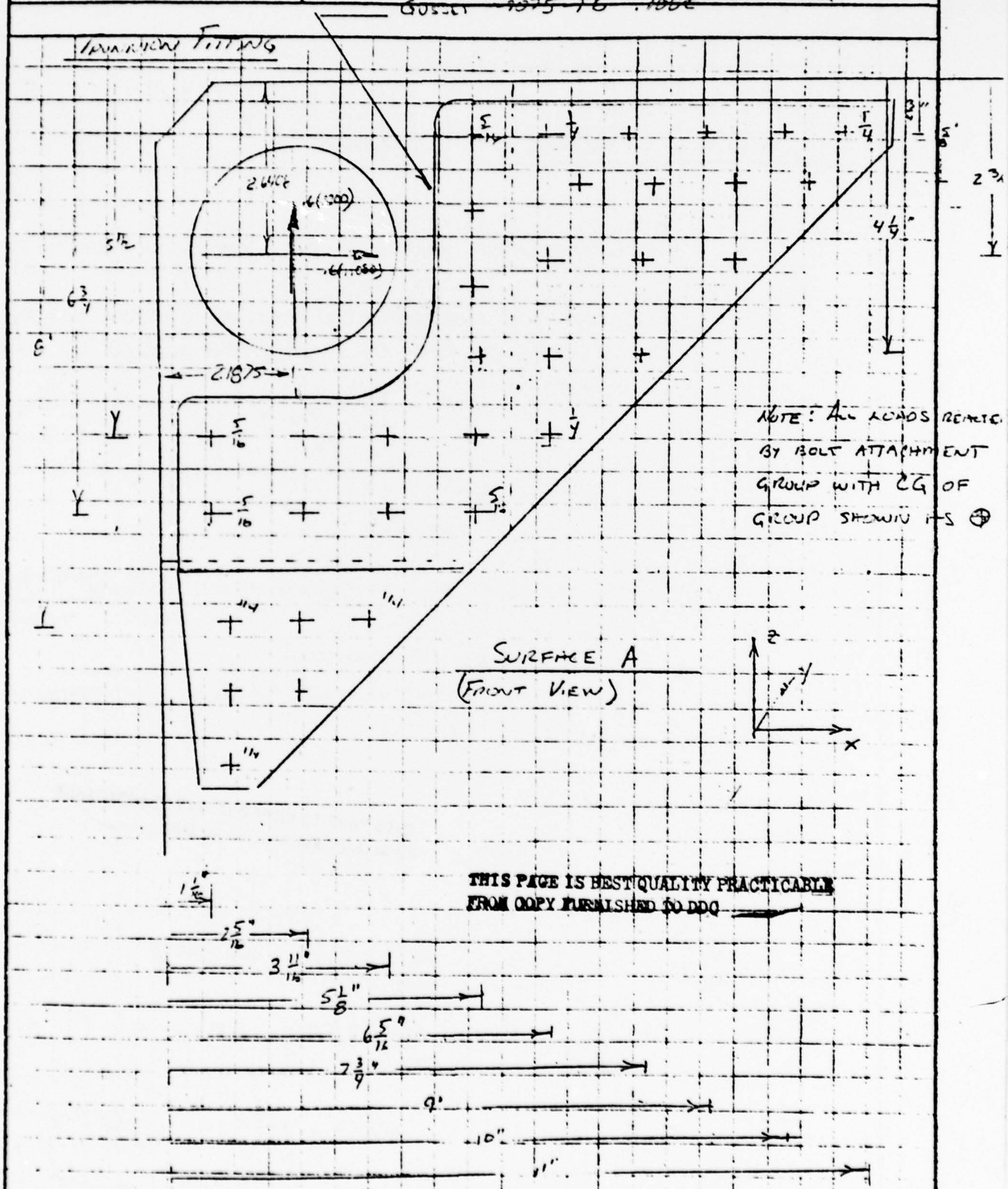
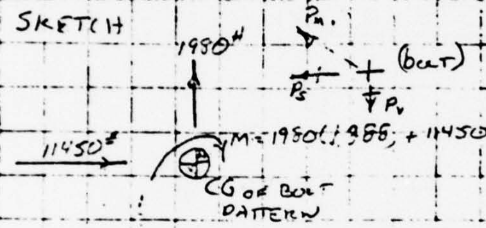


TRUNNION FITTING SURFACE A

CALCULATION OF MAXIMUM BOLT LOAD IN SURFACE A FITTING

THE MAXIMUM LOADED BOLT OCCURS IN THE UPPER RIGHT CORNER OF THE BOLT PATTERN SHOWN IN SURFACE A SKETCH

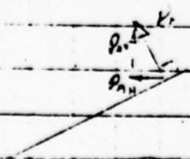


$M = 1980(1.988) + 11450(2.267) = 28,710$ in-#

P_m: FORCE ON BOLT DUE TO MOMENT $= \dfrac{M\,d}{\Sigma d^2} = \dfrac{(28710)(4.298)}{74.84} = 1650$

WHERE: M = MOMENT

d = DISTANCE TO CG OF BOLT PATTERN FROM BOLT



$P_{mv} = \dfrac{P_m \; 5.904}{6.896} = 1411$ #

$P_{mH} = \dfrac{P_m \; 3.564}{6.896} = 853$ #

Force Vertical $= 1411\# - \dfrac{1980}{12} = 1246$ #

Force Horiz $= 853 + \dfrac{11,450}{12} = 1807$ #

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TRUNNION FITTING SURFACE A

$$P_{max} = \sqrt{(1246)^2 + (1807)^2} = 2195\,\#$$

BEARING STRAIN IN FITTING

$$f_{br} = \frac{2195}{.188\left(\frac{5}{16}\right)} = 37{,}360 \text{ psi (ULTIMATE)}$$

FOR 7075-T6 $F_{BRY} = 92$ ksi MIL HDBK-5B

$F_{BRU} = 123$ ksi (ULTIMATE CRITICAL)

$$MS = \frac{123{,}000}{37{,}360} - 1 = 2.29$$

BOLT SHEAR

BOLT SHEAR ALLOWABLE = 4470 AN5

$$MS = \frac{4470}{2195} - 1 = 1.04$$

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FORM 1-8136 B (9-58)

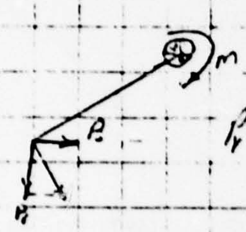
BY R. PAGE PAGE B.55

TRUNNION FITTING SURFACE A

CHECK OF FORCES ON BOLT IN LOWER LEFT CORNER

$d = \sqrt{2.51^2 + 1.842^2} = 3.11$

$P_m = \frac{Md}{\Sigma d^2} = \frac{(28710)(3.11)}{74.84} = 1193.^{\#}$



P_V MOMENT FORCE VERTICAL $= \frac{1193}{3.11} 2.51 = 963^{\#}$

P_S M. F. HORIZONTAL $= \frac{1193}{3.11} 1.842 = 706.6^{\#}$

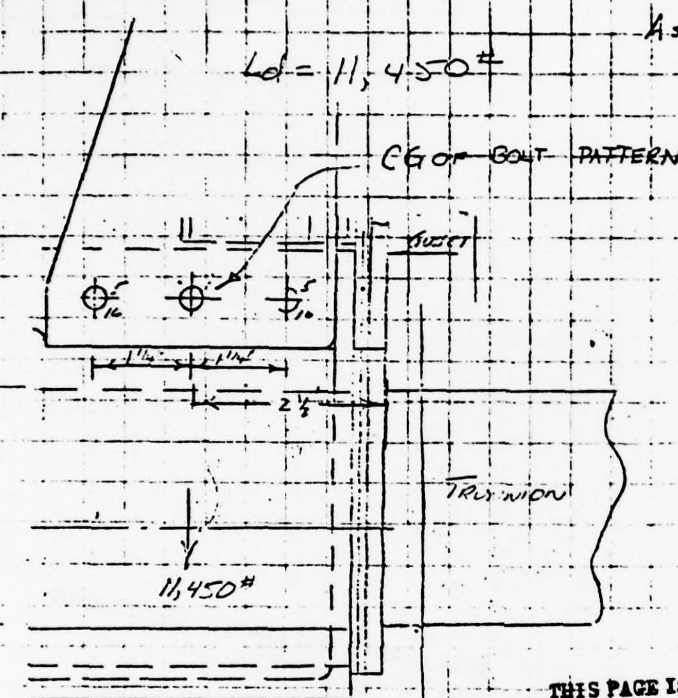
MAXIMUM FORCE VERTICAL $= 963 + \frac{1980}{12} = 1128^{\#}$

MAXIMUM FORCE HORIZ $= \frac{11,450}{12} + 706.6 = 1660$

$P_{ALLOW} = 2000$ NOT CRITICAL

TRUNNION FITTING SURFACE B

Assuming first three bolts react loading



Force on each bolt due to shear = P/no. of bolts

The maximum force on bolt $= \frac{11450^{\#}}{3} = \underline{3820^{\#}}$

BOLT SHEAR

Allowable $= 4470^{\#}$

$M.S. = \frac{4470}{3820} - 1 = \underline{0.17}$ * see page B-44

BEARING

$f_{br} = \frac{3820}{.188(\frac{5}{16})} = 65000 psi$ (ult)

$M.S. = \frac{123}{65} - 1 = \underline{0.89}$ (ult) *

FORM 1-9136 B (9-38)

BY J. F. ALTPATER | PAGE

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SURFACE B BOLTS FOR FLIGHT CONFIGURATION MS = 1.00

MAXIMUM SHEAR LOAD = 3820

FOR 5/16 BOLT AREA = .0767 in^2

FOR MS=1 SHEAR STRENGTH = $\frac{3820 \times 2}{.0767}$ = 99,608 psi

USE: NAS 1588-5

THE NON-CRITICAL BEARING STRESS ARE > 1.0 ALSO

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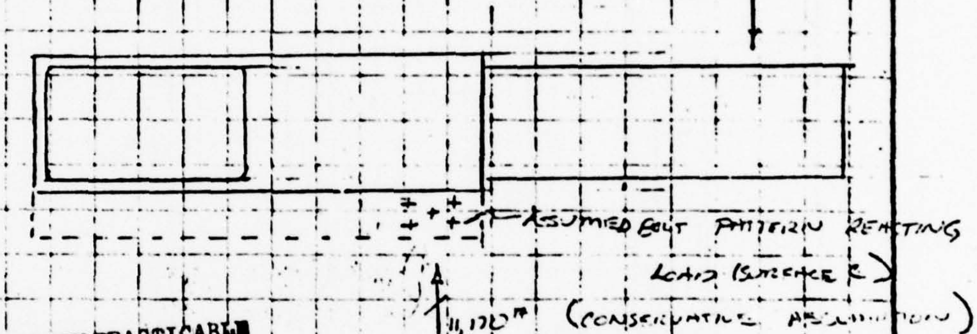
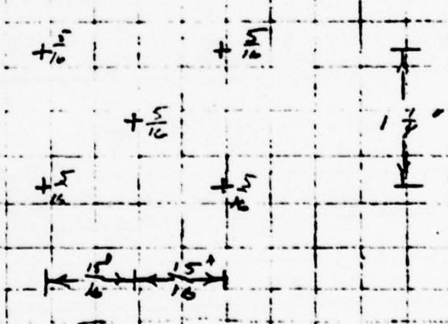
Trunnion Fitting Surface C

Maximum Total Load = 11,170# (subcase 7)



Bolt Pattern



Bolt Shear

Allowable for AN5 = 4470#

$P = \frac{11,170}{5} = 2234\#$

$MS = \frac{4470}{2230} - 1 = \underline{\underline{1.00}}$ Shear

Bearing.

Allowable for 6061-T6 = 123 ksi

$f_{br} = \frac{2234}{.188(5/16)} = 38030 \text{ psi}$

$MS = \frac{123}{38} - 1 = \underline{\underline{2.23}}$ Bearing

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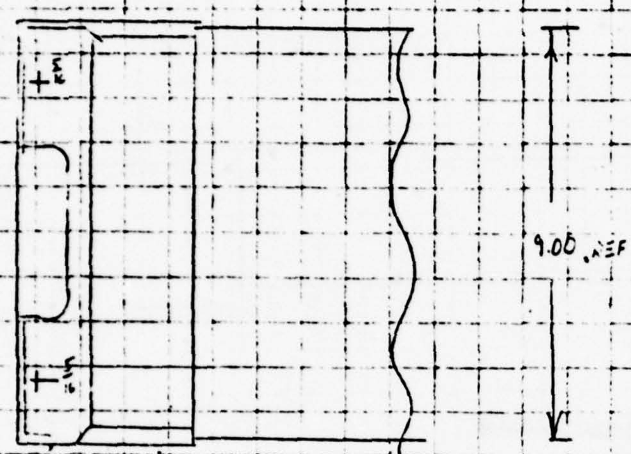
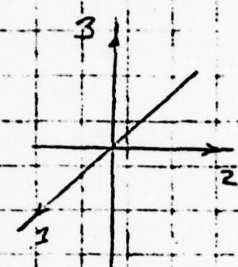
Bridge Fitting





Examination of 5/16 bolts holding bridge to STR body

Nodes which represent bridge fitting bolts

301 302
308 309
310 311
317 318

Summary of Maximum Forces on Bridge Bolts

Direction	Load Case	Grid	Force
T1	6	309	2794
T2	7	309	7166
T3	8	308	-3880.1

FORM 1-8136 B (9-68)

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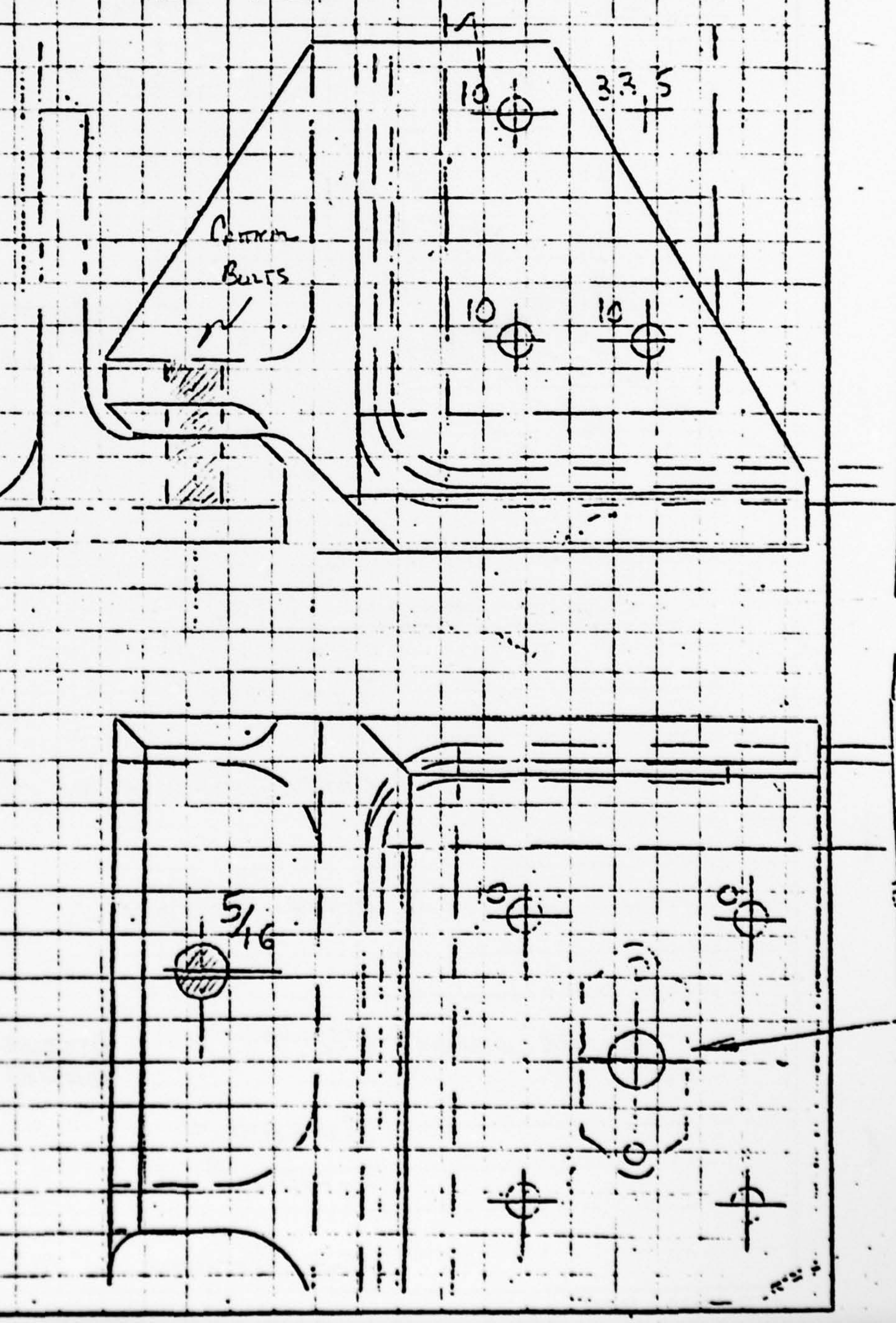
Bridge Fitting

Stress Analysis of Bridge Bolts

Top View

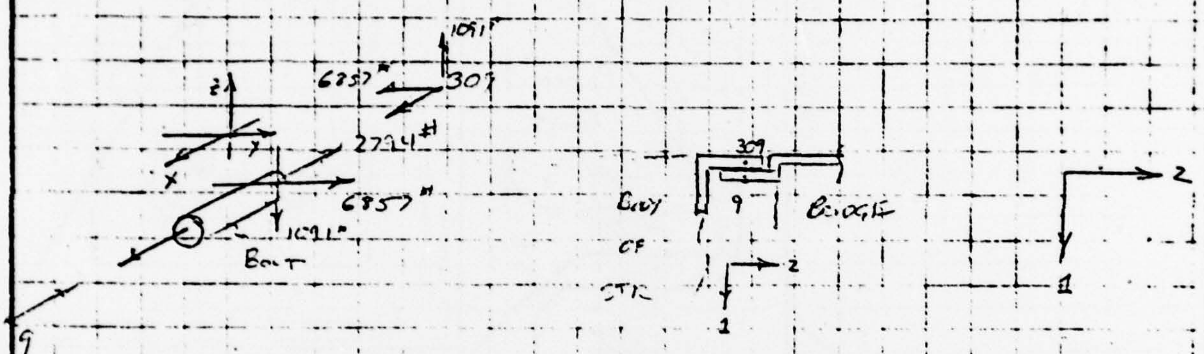


BRIDGE FITTING

STRESS ANALYSIS OF BRIDGE BOLTS (AN5)

GHG 309 - LOAD CASE 6 - MAXIMUM FORCES T1, R2, R3

$T1 = 2794^{\#}$ $T2 = -6857^{\#}$ $T3 = 1091^{\#}$



AXIAL LOAD (T1)

$T_1 = 2794^{\#}$

RATED STRENGTH FOR AN5 = 6500# TEN. ULT
4980# YIELD

$$MS = \frac{6500}{2794} - 1 = \underline{\underline{1.33}}$$

SHEAR LOADS (T2, T3)

$T_2 = 6857^{\#}$
$T_3 = 1091^{\#}$

RATED STRENGTH FOR AN5 = 5750#

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TOTAL SHEAR LOAD $= \sqrt{6857^2 + 1091^2} = 6943^{\#}$

$$MS = \frac{5750}{6943} - 1 = \underline{\underline{-.17}} \text{ (SHEAR)}$$

FOR 3/8 BOLTS A286 (SHEAR ALLOWABLE = 9945#)

$$MS = \frac{9945}{6943} - 1 = \underline{\underline{0.43}} \text{ (SHEAR)}$$

CHECK OF BEARING STRESS OF AN5

$$f_b = \frac{P}{Dt} = \frac{6943}{5/16\,(.75)} = 29{,}600 \text{ psi (ULT)}$$

FOR 7075-T6 $F_{BRY} = 92$ ksi

$F_{BRU} = 123$ ksi (ULT CRITICAL)

$$MS = \frac{123}{29.6} - 1 = \underline{\underline{3.16}} \text{ BEARING}$$

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GRID 309 - LOAD CASE 7 (MAX FORCE T2)

AXIAL LOAD

$T_1 = 1939^{\#}$

$MS = \frac{6500}{1939} - 1 = \underline{\underline{2.35}}$ TENSION

SHEAR LOAD

$T_2 = 7165$ $\quad T3 = 540$

TOTAL SHEAR LOAD $= (7165^2 + 540^2)^{1/2} = 7190^{\#}$

$MS = \frac{5750}{7190} - 1 = \underline{-.20}$ SHEAR

FOR A A286 - 3/8" BOLT (SHEAR ALLOWABLE = $9945^{\#}$)

$MS = \frac{9945}{7190} - 1 = \underline{0.38}$

THIS ANALYSIS INDICATES EITHER THE BOLT SIZE AND STRENGTH BE INCREASED OR THE FITTING BE REDESIGNED TO REDUCE THE BOLT SHEAR

BRIDGE FITTING BOLTS FOR FLIGHT CONFIGURATION MS=1.00

MAXIMUM SHEAR LOAD = 7190#

FOR 3/8" BOLT AREA = .110

THE ALLOWABLE SHEAR STRENGTH = $\frac{7190}{.110}$ = 65,360 psi

FOR A MS = 1 SHEAR STRENGTH = 65,360×2 = 130,700 psi

SHEAR BOLT WHICH WILL MEET THIS REQUIREMENT = EWSC 922-6 ALLOY STEEL SHEAR STRENGTH = 132,000 psi

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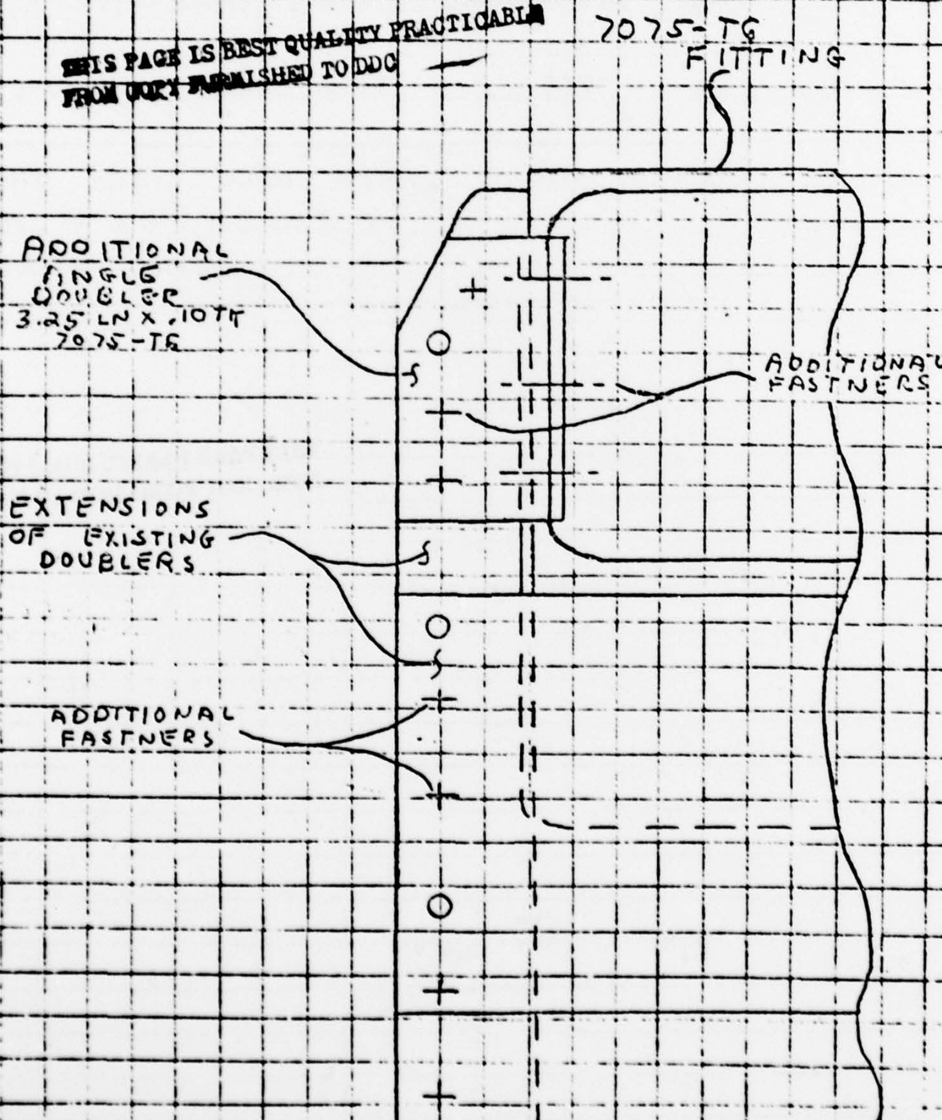
BRIDGE FITTING BOLTS

CHECKING BACKUP STRUCTURE ON STR ARCH STRUCTURE TO CARRY SHEAR LOADS FROM BOLTS ~

THE ADDITION OF A DOUBLER ANGLE AND AN EXTENSION OF EXISTING DOUBLER IS NECESSARY TO STRUCTURE SHOWN ON D/N L47J236237 SHT.13 TO PROVIDE A M.S. OF 1.0, AS SHOWN BELOW ~



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BRIDGE FITTING BOLTS

CHECKING THIS ADDITIONAL ANGLE DOUBLER IN TENSION ~

$P_t = 7165$ LBS

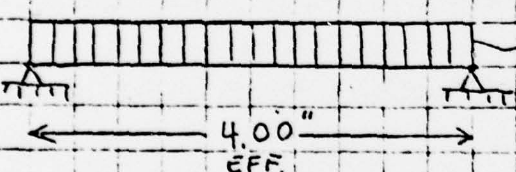
$A = 3.25 \times .10 = .325 \text{ IN}^2$

$f = \frac{7165}{.325} = 22 \text{ KSI}$

$F_{TU} = 77$ KSI FOR 7075-T6

$MS = \frac{77}{22} - 1 = \underline{\underline{+2.50}}$

CHECKING END OF TRUNNION FITTING, ASSUMING IT CARRIES 40% OF LOAD (ANGLE CARRIES 60%) ~



$W = .4 \times 7165 = 2866$#

$M = \frac{1}{8} \times 2866 \times 4.0 = 1433$ "#

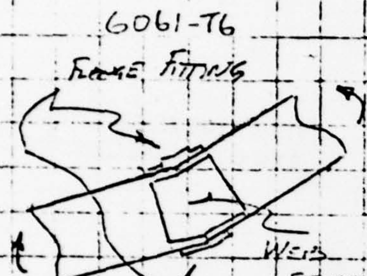
$f_B = \frac{6 \times 1433}{2.5 \times .25^2} = 55 \text{ KSI}$

$F_B = 110$ KSI

$MS = \frac{110}{55} - 1 = \underline{\underline{1.00}}$

FORM 1-6136 B (9-58)

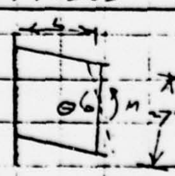
KNEE FITTING ON 9" CHANNEL



THE DESIGN OF THIS JOINT INDICATES THE FLANGE FITTING SHOULD CARRY MOMENT AND THE WEB FITTING SHOULD CARRY THE SHEAR LOAD.

HOWEVER, THE FLANGE FITTING HAS A BEND WHICH PRODUCES A KICK FORCE WHICH IS NOT REACTED. THEREFORE, THE LOAD DISTRIBUTION BETWEEN THE WEB AND FLANGE FITTINGS WILL BE ACCOMPLISHED BY RELATIVE STIFFNESSES.

STIFFNESS OF WEB FITTING RESISTING MOMENT



$$\theta = \frac{ML}{EI} = \frac{ML}{E(\frac{1}{12})(.1)(7)^3} = .350\frac{ML}{E}$$

$L = 1"$ $E = 10^7$ $M = 1$ in-#

$$\theta_w = \frac{.350}{10^7} = 3E-8$$

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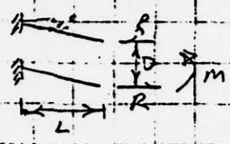
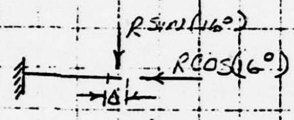
KNEE FITTING ON 9" CHANNEL

STIFFNESS OF FLANGE FITTING IN RESISTING MOMENT



$$R = \frac{M}{D} = \frac{M}{9.3''}$$



$$\Theta = \frac{\Delta}{9.3''}$$

FROM: ROARK 3RD EDITION FOR A CANTILEVER BEAM UNDER AXIAL COMPRESSION AND TRANVERSE END LOAD

$$\text{Max } y = -\frac{W}{P}\left(j \tan U - l\right)$$

WHERE: $y = \Delta$ $\quad U = \frac{l}{j}$

$W = R \sin 16°$

$P = R \cos 16°$

$j = \sqrt{\frac{EI}{P}}$

$I_{FITTING} = \frac{1}{12}(3.1)\left(\frac{1}{4}\right)^3$

$= .00404 \text{ in}^4$

$l_{FITTING} \approx 1''$ AVE. LENGTH TOP & BOTTOM

CHECKING MAGNITUDE OF U $\quad j \approx \sqrt{\frac{10^7(.00404)}{\frac{6E4 \cos 16°}{9.3}}} = 2.55$

(6E4 MOMENT FROM 9" CHANNEL CHECK) $\quad l \approx 1''$

$$y = \frac{\sin 16°}{\cos 16°}\left(2.55 \tan \frac{1}{2.55} - 1\right) = .0157 \text{ in} \quad \text{FOR } M = 6E4$$

$$y_{1M} = \frac{.0157}{6E4} = 2.611\,E\text{-}7$$

$$\Theta_F = \frac{2.611\,E\text{-}7}{9.3/2} = 5.615\,E\text{-}8 \text{ RADS}$$

KNEE FITTING ON 9" CHANNEL

$$\frac{\Theta_{FLANGE}}{\Theta_{WEB}} = \frac{5.615E-8}{3\ E-8} = 1.9 \approx \frac{2}{1}$$

∴ IT WILL BE ASSUMED THAT THE WEB WILL CARRY 1/3 THE MOMENT IN THE 9" CHANNEL WITH THE FLANGES CARRYING THE REMAINDER.

FROM THE 9" CHANNEL ANALYSIS THE MAXIMUM STRESS CONDITION OCCURS IN LOAD CASE 8

$T2 = 2650^{\#}$
$F3 = 705^{\#}$
$R1 = 60{,}000$ in-#

CHECK OF STRESS IN 9" CHANNEL DUE TO MOMENT IN WEB

$$\sigma_b = \frac{Mc}{I} = \frac{\frac{1}{3}(60{,}000)\left(\frac{9}{2}\right)}{\frac{1}{12}(.4)(9)^3} = 14{,}800\ psi$$

$$MS = \frac{42}{14.8} - 1 = \underline{1.8}$$

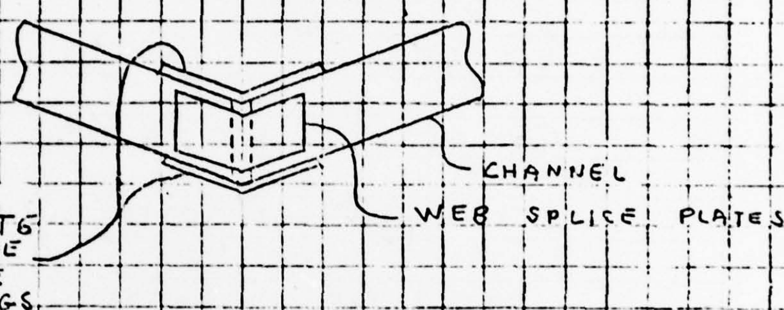
BEARING

$$f_{br} = \frac{3820}{.188(\frac{5}{16})} = 65000 psi \text{ (ult)}$$

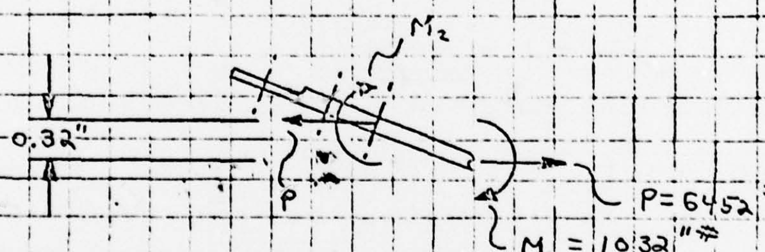
$$M.S. = \frac{123}{65} - 1 = \underline{0.89} \text{ (ult)} *$$

FORM 1-8136 B (8-58)

KNEE FITTINGS ON 9" CHANNEL



CHECKING THE LOWER FLANGE SPLICE FITTINGS, CONSERVATIVELY ASSUMING THAT FLANGE SPLICE CARRIES ENTIRE MOMENT IN BEAM AT JOINT ~



LOADING FROM LOAD CASE # 8 AT GRID # 39 WILL BE THE MOST CRITICAL DUE TO HIGH MOMENT ~

$$P = \frac{60,000}{9.3} = 6452 \text{ LBS}$$

ASSUMING THAT $M_1 = M_2$ ~

$$M_1 = M_2 = \frac{1}{2} \times .32 \times 6452 = 1032 \text{ IN-LBS}$$

NOTE: THE EFFECT OF LOADS T2 + T3 HAS BEEN NEGLECTED IN THE ABOVE SINCE THEY ARE SMALL IN COMPARISON TO THE MOMENT R1,

KNEE FITTINGS ON 9" CHANNEL

CHECKING BENDING + TENSION STRESSES IN FLANGE SPLICE FITTING ~

$t = .25$ IN $W = 3.1$ IN

$A = .25 \times 3.1 = 0.78 \text{ IN}^2$

$$I = \frac{3.1 \times .25^3}{12} = 0.00404 \text{ IN}^4$$

$$f = \frac{1032 \times .125}{.00404} + \frac{6452}{.78} = 31.9 + 8.3$$

$= 40.2$ KSI

$F_{BU} = 62$ KSI

$$MS = \frac{62}{40.2} - 1 = \underline{\underline{+0.54}}$$

FOR MS ≥ 1.0, INCREASE THICKNESS TO ≥ 0.28

NOTE THAT THE UPPER FLANGE SPLICE FITTING IS IDENTICAL TO THE ABOVE FITTING AND SINCE THE LOADS ARE LOWER (49,000"# AS OPPOSED TO 60,000"#) WILL HAVE A GREATER MARGIN OF SAFETY THAN THAT SHOWN ABOVE.

DUE TO GEOMETRY AND BOLT LOCATIONS THE LOWER FLANGE SPLICE FITTING WILL BE LESS CRITICAL THAN THE ABOVE.

KNEE FITTINGS ON 9" CHANNEL

CHECKING BEARING STRESSES IN FLANGE OF 9" CHANNEL DUE TO BOLT SHEAR ~

$$S_{BOLT} = \frac{\cos 16^\circ \times \frac{2}{3} \times 6452}{7} = 591 \text{ LBS/BOLT}$$

$$f_{BR} = \frac{591}{.10 \times .25} = 23.4 \text{ KSI}$$

$$F_{BRU} = 67 \text{ KSI}$$

$$M.S. = \frac{67}{23.4} - 1 = \underline{\underline{+1.87}}$$

CHECKING FLANGES OF 9" CHANNEL AND CROSS WEB REACTING TENSION LOADS FROM BOLTS

$$P = \frac{2}{3} \times \left(\frac{\sin 16^\circ \times 6452}{7} + \frac{103.2}{1.4 \times 3} \right) = 330 \text{ LBS/BOLT}$$

$$M \approx \frac{1}{8} \times 330 \times 1.7 = 70 \text{ IN-LBS}$$

$$f_B = \frac{6 \times 70}{1.1 \times .1^2} = 38.2 \text{ KSI}$$

$$F_B = 62.2 \text{ KSI} \quad \text{FOR } k = 1.5 \text{ (RECT. SEC)}$$

$$MS = \frac{62.2}{38.2} - 1 = \underline{\underline{+.63}}$$

ADDING A 0.10 IN THICK RADIUS BLOCK ~

$$f_b = \frac{6 \times 70}{1.1 \times .15^2} = 17 \text{ KSI} \qquad MS = \frac{62.2}{17} - 1 = \underline{\underline{+2.66}}$$

THE LOADS CALCULATED ABOVE INDICATE THAT THE BOLTS THEMSELVES WILL HAVE AMPLE STRENGTH IN BOTH TENSION AND SHEAR.

KNEE FITTING ON 9" CHANNEL

CHECKING BOLTS IN WEB SPLICE PLATE

LOCATION OF CG OF BOLT PATTERN

A	$\bar{Y}$	$A\bar{Y}$	FROM CG Y LOCATION OF BOLT	$A\bar{X}$	FROM CG X LOCATION OF BOLT
1	0	0	3.99	.5	1.59
1	1.25	1.25	2.74	1.5	.59
1	2.6	2.6	1.39	3.0	-.91
1	3.9	3.9	.09	3.9	-1.81
1	5.2	5.2	-1.21	.5	1.59
1	7.8	7.8	-3.81	1.5	.59
1	7.0	7.0	-3.01	2.7	-.61
1	1.3	1.3	2.69	3.8	-1.71
1	5.5	5.5	-1.51	2.5	-.41
1	8.05	8.05	-4.06	.5	1.59
1	.3	.3	-3.69	3.8	-1.71
1	3.9	3.9	.09	.5	1.59
1	7.2	7.2	-3.21	2.0	.09
1	2.45	2.45	1.54	3.5	-1.41
1	4.85	4.85	-.86	2.6	-.51
1	1.7	1.70	2.29	.5	1.59
1	8.35	8.35	-4.36	1.6	.49
1	.75	.75	3.24	3.3	-1.21
1	7.5	7.5	-3.51	1.1	.99
1	6.0	6.0	-2.01	2.1	-.01
1	4.4	4.4	-.41	3.1	-1.01
1	2.8	2.8	1.19	.95	1.14
1	2.0	2.0	1.99	1.9	.19
1	1.0	1.0	2.99	2.9	-.81
$\Sigma A = 24$		$\Sigma A\bar{Y} = 95.8$		50.25	

$\bar{Y} = \frac{95.8}{24} = 3.99"$ $\qquad \bar{X} = \frac{50.25}{24} = 2.09"$

KNEE FITTING ON 9" CHANNEL

DETERMINATION OF MAXIMUM SHEAR STRESS IN BOLT. IN WEB

$$\text{LOAD MAX DUE TO MOMENT} = \frac{Md}{R}$$

$$R = \Sigma H^2 + \Sigma V^2 = 31.8 + 169.0 = 201$$

$$d_{max} = \left\{(8.32-3.99)^2 + (2.90-2.09)^2\right\}^{\frac{1}{2}} = 4.41"$$

$$Ld_{max} = \frac{(60,000)(4.41)}{201} = 1315^{\#}$$

$$\text{LOAD DUE TO SHEAR (T2)} = \frac{2650}{24} = 110^{\#}$$

$$\text{LOAD DUE TO SHEAR (T3)} = \frac{705}{24} = 29^{\#}$$

$$\text{TOTAL SHEAR ON BOLT} = \left[\left\{1315 + 29\left(\frac{.81}{4.41}\right) + 110\left(\frac{4.33}{4.41}\right)\right\}^2 + \left\{29\left(\frac{4.33}{4.41}\right) - 110\left(\frac{.81}{4.41}\right)\right\}^2\right]^{\frac{1}{2}}$$

$$= 1430^{\#}$$

ALLOWABLE SHEAR STRENGTH FOR AN4 BOLT = 3680#
(FOR 2117-T3) BRUHN (p. D1.20)

$$MS_{SHEAR} = \frac{3680}{1430} - 1 = 1.6$$